Hydrologic Investigation of the Louisiana Chenier Plain

Prepared for the

Louisiana Coastal Wetlands Conservation and Restoration Task Force

by the

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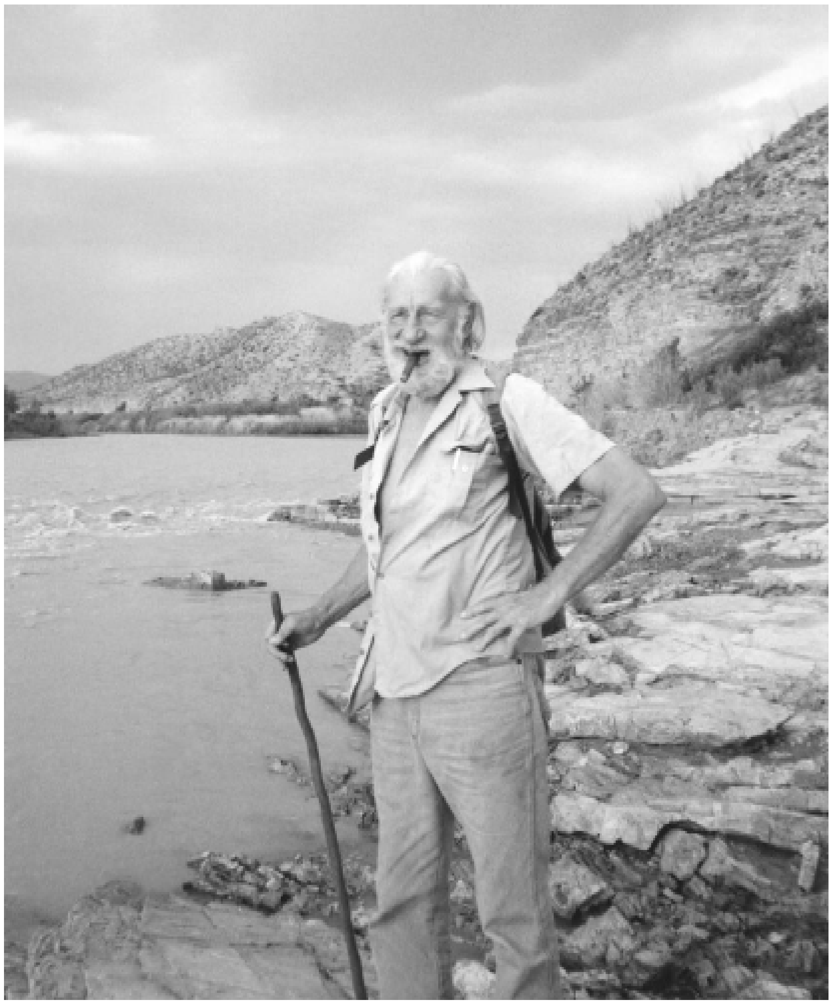
Dedication

This publication is dedicated to the memory of Mr. Jacob "Jake" Valentine (1917-2000) for his contributions to the field of biology and lifetime dedication to protecting the natural resources of the Northern Gulf of Mexico coastal region. (Photo courtesy of Jake's wife, Orpha Valentine.)



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EXECUTIVE SUMMARY

This study began in April 1999 at the direction of the Coastal Planning, Protection and Restoration Act (CWPPRA) Task Force. We believe that providing a better understanding of the hydrology of the Louisiana Chenier Plain is essential to implementing successful ecosystem-scale wetland restoration projects. To that end, we concentrated on the analysis of existing long- and short-term hydrographic records, and supplemented those with recent marsh elevation data, landscape change analysis, and hydrologic modeling. We also examined natural resource management practices by interviewing wetland managers and reviewing historical natural resource management records. We present here an overview of the chenier plain ecosystem and a general description of previous basin-scale characterizations, studies, and restoration plans. We then address the specific characteristics and management issues of the Mermentau and Calcasieu-Sabine basins individually

Mermentau Basin

The Lower Mermentau Basin comprises two sub-basins, the Lakes Sub-basin, located immediately south of the limit of the coastal zone and north of Louisiana Highway 82, and the Chenier Sub-basin, which lies between Louisiana Highway 82 and the Gulf of Mexico. Construction of navigation channels, locks, and water control structures has altered the historical north-south river and tidal-driven hydrology and shifted it to an east-west system that drains through the Gulf Intracoastal Waterway navigation channels. One result of these changes is that the Mermentau Lakes Sub-basin now functions more as a freshwater reservoir and less as the low-salinity estuary it was prior to these alterations.

U.S. Army Corps of Engineers (USACE) locks and water control structures that are located along the perimeter of the Lakes Sub-basin regulate both salinity and water level. Data analyses of historical stage records from these structures indicate that water level is rising both inside and outside of the sub-basin. The rates of rise are irregular both over time and among the structures. Over a nearly 50-yr period of record, water levels inside the sub-basin have risen an average of approximately 0.16 in/yr, and water levels outside the sub-basin have risen an average of approximately 0.27 in/yr.

Many natural resource managers have long believed that the USACE-operated locks and control structures have resulted in elevated water levels and prolonged marsh flooding that is slowly drowning the marsh in the Lakes Sub-basin. Although elevated water levels and prolonged marsh flooding have been named as the major cause of land loss in several restoration plans and restoration planning documents, we believe there has been no scientific documentation of this phenomenon occurring at a systemic scale in the Mermentau Basin.

The contention that prolonged marsh flooding causes plant stress and/or death in the Lake Sub-basin remains unproven. Four key pieces of evidence indicate that prolonged marsh flooding in the Lakes Sub-basin may not be a primary cause of wetland loss:

- *Rates of water level rise in the Mermentau Lakes Sub-basin do not exceed the reported ability of fresh and intermediate marshes to maintain elevation in response or relation to a rising sea;*
- *Historical causes of landscape change in the Lakes Sub-basin include causes of loss other than prolonged marsh flooding (e.g., produced-water discharge, saltwater intrusion, wetland and wildlife management practices, and shoreline erosion);*
- *Analysis of land cover change revealed a slight overall increase in wetland area in the Mermentau Basin over the period 1990-96, indicating relative wetland landscape stability; and,*
- *Analyses of 14 years of water level records taken hourly at each of the control structures suggest that, except at marshes in the vicinity of the Catfish Point control structure, marsh flooding does not appear to be excessive over the long term.*

The historical water level record clearly indicates that marshes in the vicinity of Catfish Point do experience prolonged flooding. Despite this, land loss maps show very little change in these marshes over the period 1978-96, which suggests that these marshes are fairly flood-tolerant. We submit that a series of human-induced hydrologic changes relating to navigation, salinity, and water level control—both individually and acting together—have caused the observed flooding of marshes in the vicinity of Catfish Point.

Currently, multiple projects under various phases of planning share, at least in part, the common goal of removing excessive water from the marshes in the Lakes Sub-basin. We recommend that, in light of our findings, the CWPPRA program proceed cautiously with these projects and evaluate other factors that may be causing landscape deterioration. The timing and duration of marsh flooding need to be understood at both the ecosystem scale and at the level of plant-substrate interaction. The general understanding of the relationship between marsh stability, marsh elevation, and surface flooding is, at best, incomplete. Basic applied research is needed to document the chemical-physical relationship between marsh flooding and plant health in this area. This would be consistent with other ongoing programmatic efforts to improve project effectiveness, including the use of adaptive management, hydrodynamic modeling, and detailed ecological review during the project planning phase.

Calcasieu-Sabine Basin

The Calcasieu-Sabine Basin was historically interconnected with the Mermentau Basin, but human-induced hydrologic alterations caused by navigation corridors have made the two basins more hydrologically distinct. The Sabine-Neches Ship Channel and the Calcasieu Ship Channel have been expanded incrementally to the extent that the present-day channel cross-sectional areas are more than forty times larger than when first dredged in the late 1800s. These changes have affected hydrology by three principle means: channeling saltwater into the historical low-salinity estuary; creating a channelized loss of riverine inflows when the tide ebbs; and increasing tidal amplitude.

Construction of the Gulf Intracoastal Waterway bisected the Gum Cove Ridge that historically was a hydrologic barrier separating the Calcasieu and Sabine basins. This caused a hydrologic coupling of the two basins by connecting the Calcasieu Ship Channel and the Sabine-Neches Ship Channel. This connection dramatically altered hydrologic circulation by disrupting the historical north-south estuarine gradient and diverting to the east and west riverine inflows and saltwater intrusion induced via navigation channels.

In general, the salinity regime in the Calcasieu-Sabine Basin is reflected in the marsh habitat types that exist there today. Habitat shift analyses reveal no basin-wide shift toward a more saline environment since 1949, although some site-specific shifts toward more saline environments have occurred adjacent to the Calcasieu Ship Channel. We have shown that the salinity regime varies substantially both spatially and temporally at the seasonal, annual, and decadal time scales. A strong negative correlation between Sabine River discharge and salinity across the basin indicates that the Sabine River, more so than the Calcasieu River, is the primary influence on moderating salinities across most of the basin.

Two ongoing planning activities in Texas may jeopardize Sabine River inflows into the Calcasieu-Sabine Basin. The first is our primary concern, a proposal by the Jefferson County Navigation District of Beaumont, Texas, to expand the Sabine-Neches Ship Channel from the Gulf of Mexico to the Port of Beaumont. A wider, deeper channel would likely exacerbate saltwater intrusion during flood tide and freshwater outflow as the tide ebbs. This combination would make less freshwater available to area marshes. Hydrologic model simulations of this channel expansion indicate a resulting salinity increase sufficient to cause wetland habitat shifts to more brackish conditions, and a probable loss of land. We show through model simulations that maintaining a historical channel cross-section and a navigable gate at Sabine Pass reduces salinity sufficiently to cause habitat shifts to fresher conditions.

Our other cause for concern arises from the draft East Texas Water Plan. Although this plan's projected inflow reduction is relatively small, its environmental impact should be considered along with that of a deeper ship channel. Also, industrial and municipal water supplies may be threatened by saltwater intrusion.

The data we discuss here indicate that the ecological sustainability of the Calcasieu-Sabine estuary continues to deteriorate and is imperiled by saltwater intrusion induced through navigation channels. This deterioration will probably be accelerated by the deepening of the Sabine-Neches Ship Channel. We propose that the most effective means of protecting the Calcasieu-Sabine system is through restoring a more natural hydrology at junctions of the Calcasieu-Sabine estuary with the Gulf of Mexico. This restoration effort would entail installing navigable gates or locks at the mouths of the Sabine-Neches Ship Channel and the Calcasieu Ship Channel while maintaining more historical channel cross-sections to allow improved drainage and organism ingress and egress. State-of-the-art technology could be employed to minimize or avoid the obvious conflicts with ships that require deep-draft channels to conduct commerce. Both environmental and business interests will benefit by focusing less on conflicts between ecosystem integrity and economic gain, and more on finding solutions that are workable and mutually acceptable.

INTRODUCTION

Wetland ecosystems in Louisiana's Chenier Plain are undergoing persistent deterioration that will become increasingly catastrophic if not adequately addressed. We based our study on the tenet that a more holistic understanding of the hydrology of Louisiana's Chenier Plain is essential to the successful development and implementation of technically sound ecosystem-level restoration strategies for this region. We concentrated on the analysis of existing long- and short-term data records of water level, salinity, wind and rain, and riverine inflow, and we supplemented these analyses with new data on marsh elevation. We also examined current and past natural resource management practices by interviewing marsh managers and reviewing archived narrative reports from the Sabine National Wildlife Refuge. Additionally, we employed hydrologic modeling to better understand the effects of potential hydrologic alterations that may impact the biological productivity and ecosystem sustainability of the Calcasieu-Sabine Basin, the western portion of Louisiana's Chenier Plain. We characterize here the Mermentau and Calcasieu-Sabine basins individually, and address the specific environmental challenges and management issues faced by each basin.

Study Area

Our study area comprises the Louisiana Chenier Plain, which extends from the western bank of the Freshwater Bayou Canal westward to the Louisiana-Texas border in Sabine Lake, and from the marsh areas just north of the Gulf Intracoastal Waterway (GIWW) south to the Gulf of Mexico in Vermilion, Cameron, and Calcasieu parishes (Figure 1). It consists of approximately 2,402 mi^2 of marsh, open water, and chenier habitats. Marsh types, their associated land cover across the region, and the percent of total marsh coverage represented by each type are: fresh marsh, 554 mi^2 (47 %); intermediate marsh, 264 mi^2 (22%); brackish marsh, 310 mi^2 (26%); and saline marsh, 52 mi^2 (4%; Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority [LCWCRTF/WRCA 1998]).

Two major hydrologic basins, the Mermentau and the Calcasieu-Sabine, compose the Louisiana Chenier Plain (Figure 1). The Mermentau River Basin, in southwestern Louisiana, can be divided into three sub-basins: Upland, Lakes, and Chenier. The Upland Sub-basin covers an area of 3,683 mi^2 of predominantly agricultural land. The Lakes Sub-basin is delineated by the Freshwater Bayou Canal on the east, the limit of the coastal zone on the north, Louisiana Highway 27 on the west, and Louisiana Highway 82 on the south. Highway 82 runs atop and between the Grand Chenier-Pecan Island ridge complex. The Chenier Sub-basin lies south of this ridge complex.

The Calcasieu-Sabine Basin is a shallow coastal wetland system with freshwater input at the north end, a north-south flow through Calcasieu and Sabine lakes, and some east-west water movement through the GIWW and interior marsh canals (e.g., North Starks and South Starks canals on the Sabine National Wildlife Refuge). Calcasieu and Sabine lakes are

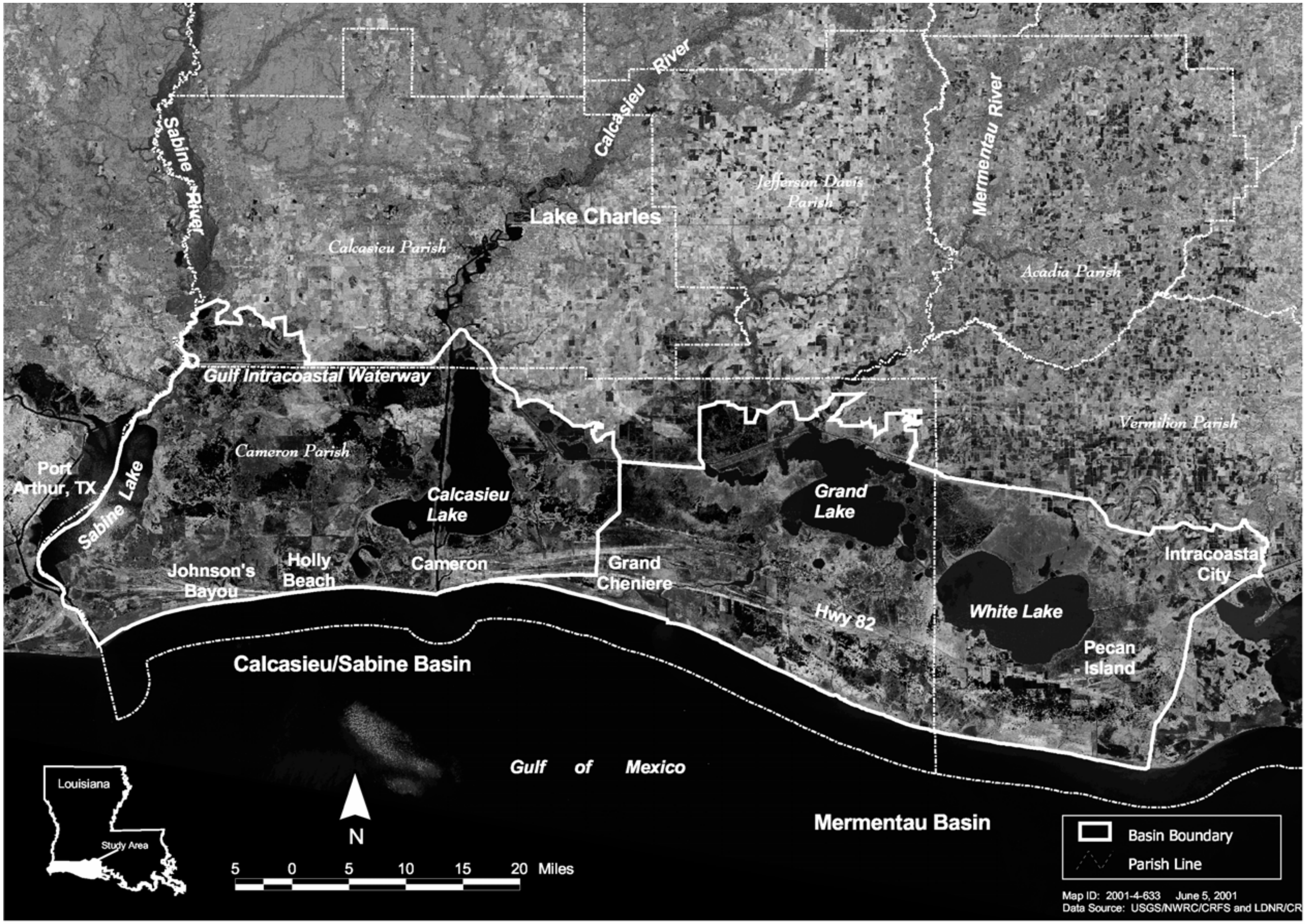


Figure 1. Study area, Louisiana's Chenier Plain.

both important corridors and are used for recreational and commercial purposes. As in the Mermentau Basin, managed wetlands are a significant feature of the Calcasieu-Sabine Basin.

Chenier Plain Geomorphology

Marshes within Louisiana's Chenier Plain began forming about 3,000-4,000 years ago during periods when the Mississippi River followed a westerly course (Gosselink et al.1979). Large quantities of riverine sediment accreted on the gulf shore, resulting in expansive mud flats. At the termination of this delta-building sequence, the river shifted more to the east and erosion reworked the gulf shoreline to form beach ridges parallel to shore. These ridges, which consisted mainly of sand and shell, were typically higher in elevation than surrounding marshes and were colonized by live oaks (*Quercus virginiana*). Early explorers called the ridges "Cheniere," a French word meaning "place of oaks" (Kniffen and Hilliard 1988). Over time, a series of Gulf of Mexico shoreline transgressions and regressions caused by periodic shifting of the Mississippi channel from east to west resulted in the shore-parallel ridge and swale topography that dominates Louisiana's Chenier Plain today.

Erosive processes dominate the Louisiana gulf shore, except at a few locations: sediment coming from the prograding Atchafalaya and Wax Lake deltas is building mud flats on the gulf shore of the southeastern Mermentau Basin, and accretion is occurring on the immediate updrift and downdrift sides of the jetties at both Calcasieu Pass and Sabine Pass (Byrnes et al. 1995). The most severe shoreline erosion in the chenier plain is occurring in the vicinity of the Rockefeller Wildlife Refuge, where the long-term shoreline erosion rate has averaged 28.5 ft/yr (Byrnes et al. 1995).

The long-term influence of continued shoreline erosion on regional hydrology is poorly understood. The primary impacts of continued erosion will likely be different in the Mermentau Basin than in the Calcasieu-Sabine Basin because of differences in the hydrology and physiography of the two basins. Erosion on the Calcasieu-Sabine shoreline may result in breaching of the last remaining chenier separating the Gulf of Mexico from the interior marshes in the vicinity of Holly Beach (Figure 1). This could potentially lead to open tidal exchange and saltwater intrusion into the brackish to intermediate marshes of the Calcasieu-Sabine estuary. No one can predict with certainty whether this breaching will occur or what the magnitude of its adverse impacts would be. The Louisiana Department of Natural Resources (LDNR) has funded a study to determine the best way to protect this portion of Gulf of Mexico shoreline. The Holly Beach (CS-01) Coastal Planning, Protection and Restoration Act (CWPPRA) project, which proposes to place sand between eight miles of existing segmented breakwaters, was recently approved for construction by the CWPPRA Task Force.

The four major lakes in Louisiana's Chenier Plain—Calcasieu, Sabine, Grand, and White lakes—were formed as bays at the mouths of drowned Pleistocene entrenched river valleys during the Holocene rise in sea level, over the past 5,000 years (Fisk 1944). The lower ends of these bays were constricted by longshore transport and deposition of

Mississippi River sediment to the extent that only small tidal passes remained prior to the 1890s. The lakes generally range from 3 to 8 ft in depth.

Previous Basin-scale Reports and Studies on the Louisiana Chenier Plain

Numerous efforts, each with somewhat different objectives, have been undertaken to improve our understanding of the Louisiana Chenier Plain ecosystem. Project objectives included characterizing the region, developing restoration plans, and conducting studies related to specific planning efforts. These studies are discussed in chronological order here.

The most comprehensive characterization of the Louisiana and Texas Chenier Plain ecosystem was conducted by James Gosselink and his colleagues at Louisiana State University (Gosselink et al. 1979). They provided an excellent overview of human-induced hydrologic alterations to the chenier plain system, and characterized the ecosystem, hydrologic sub-basin, habitat types, and animal species populations.

Gosselink et al. (1979) presented evidence that water level was rising across the chenier plain and that this trend was most distinct in the Mermentau Basin, which exhibited a long-term rise rate of 0.84 in/yr. This rise was related to three key factors. First, water control structures installed by the U.S. Army Corps of Engineers (USACE) around the perimeter of the Lakes Sub-basin altered flow, water level, and salinity regimes, resulting in the semi-impoundment of the entire sub-basin. Second, marsh impoundments designed primarily to improve conditions for waterfowl have also dramatically altered inundation and flow patterns of the Lakes Sub-basin.

The third major factor identified by Gosselink et al. (1979) as influencing water level rise in the Mermentau Basin was the withdrawal of freshwater for rice irrigation. This withdrawal amounted to approximately one-third of the Mermentau River inflow during April-June, typically during the rainfall-deficit portion of the annual precipitation cycle, when river discharge is at a minimum. It is important to note that this water volume is not entirely lost to the system because it is later returned when the rice fields are drained. Additionally, approximately one-third of the total irrigation requirement comes from groundwater. The implication of this is that the volume of water released back into the surface water system may exceed the volume withdrawn earlier in the season. Ignoring potential losses due to evapotranspiration, surface water inflows into the Lakes Sub-basin would be larger than they were before the USACE water control structures were installed (Gosselink et al. 1979).

The completion of the Louisiana Coastal Wetlands Restoration Plan in 1993 (CWPPRA 1993) represented the first joint effort between state and federal parties to develop a comprehensive coastal restoration plan for the Louisiana Chenier Plain. The plan characterized the Mermentau and Calcasieu-Sabine basins, identified known and perceived wetland loss problems facing the region, and developed basin-scale strategies to ameliorate the identified problems. From these strategies, a recommended plan of action was developed and conceptual projects with restoration potential were identified and categorized according to the degree of support for the selected strategy. CWPPRA (1993) categorized all conceptual projects—51 in the Mermentau Basin and 106 in the Calcasieu-Sabine Basin—as short-term critical projects, short-term supporting projects, or long-term supporting projects. These plans served as the guiding document for coastal restoration in the Chenier Plain for five years, until the Coast 2050 Plan was adopted in 1998.

The Natural Resources Conservation Service (NRCS), with the assistance of other federal and state agencies and local governments, completed a cooperative study of the Calcasieu-Sabine River Basin in 1994 (USDA 1994). It presents an excellent historical overview of the major anthropogenic hydrologic alterations to the ecosystem. USDA (1994) developed and evaluated three wetland management alternatives, and compared these to taking no action. Those plans included: 1) basin perimeter control with locks or floodgates on the Calcasieu Ship Channel, the Sabine-Neches Ship Channel, and the GIWW to control salinity; 2) hydrologic unit control with levees, water control structures, and shore protection in 47 different units; and 3) hydrologic unit control, supplemented in some units with additional enhancement features, such as wave stilling and sediment trapping devices and vegetative plantings. The agencies involved recommended the second plan, hydrologic unit control with levees and water control structures.

A second NRCS-led cooperative study of the Mermentau River Basin was completed in 1997 (USDA 1997). This study identified prolonged marsh flooding in the Lakes Sub-basin as a primary cause of wetland deterioration. Two management alternatives to ameliorate the perceived flooding were compared to taking no action. One alternative addressed the problem of high water levels in the Lakes Sub-basin and identified several ways of potentially improving drainage. However, none of the proposed approaches to draining the basin received more detailed reconnaissance-level evaluation because a concurrent USACE reconnaissance study, described later, was attempting to accomplish that task. The second management alternative divided the basin into 86 separate hydrologic units and called for varying combinations of water control structural features, shore protection, sediment trapping, levees, pumps, and vegetation plantings. This became the recommended alternative of the USDA (1997) study.

The USACE conducted a reconnaissance study to evaluate several different means of reducing wetland flooding in the Lakes Sub-basin (USACE 1996). This study investigated measures to restore the area's wetland fish and wildlife values to a "historical, more productive ecological condition." As with previous studies, historical wetland losses were attributed in the USACE (1996) report to high water levels in the basin, thus the study dealt only with water drainage strategies that strongly emphasized hydrologic modeling of the Lakes Sub-basin. The USACE utilized a two-dimensional finite element hydrologic model to quantify the effects of alterations on the existing drainage system and considered six major drainage improvement alternatives: 1) Constructing a new lock chamber at the Calcasieu Lock to improve drainage and navigation; 2) Installing box culverts to help drain the Mermentau Basin while bypassing the Calcasieu Lock; 3) Constructing a new north-south drainage channel with a saltwater control structure, to drain the Lakes Sub-basin and relieve marsh flooding; 4) Increasing the capacity for drainage through structure enlargements and channel improvements; 5) Increasing the capacity for drainage through channel enlargement; and, 6) Forcing drainage through the use of pumps.

The Wetland Value Assessment model was used to estimate the wetland habitat benefits of the modeled alternative plans and to screen out alternatives that were not recommended for future feasibility analysis (USACE 1996). In the end, the USACE recommended constructing a drainage channel with a saltwater control structure, based on the predicted reduction that would take place in water level and the subsequent environmental benefits to the Lakes Sub-basin.

The most recent ecosystem-level planning effort, known as Coast 2050, developed a coastal plan backed by state, federal, and local interests that provided a clear set of restoration strategies (LCWCRTF/WRCA 1998). The Coast 2050 process ensured effective public input to restoration planning and integrated restoration projects into the overall coastal management system. The Coast 2050 coastal restoration plan seeks to achieve three strategic objectives:

- To sustain a coastal ecosystem with the essential functions and values of the natural ecosystem;
- To restore the ecosystem to the highest practicable acreage of productive and diverse wetlands; and,
- To accomplish this restoration through an integrated program that has multiple-use benefits, not solely for wetlands, but for all the communities and resources of the coast.

The Coast 2050 planning effort involving the Louisiana Chenier Plain focuses on developing strategies, not specific projects. To this end, a series of ecosystem-level strategies center primarily on hydrologic management to control salinity, improve growth conditions for emergent wetlands, and provide for shoreline protection.

The 1993 Louisiana Coastal Wetlands Restoration Plan (CWPPRA 1993), the NRCS Mermentau cooperative River Basin study (USDA 1997), the USACE Lakes Sub-basin reconnaissance study (USACE 1996), and the Coast 2050 plan (LCWCRTF/WRCA 1998) all cite elevated water levels as the leading cause of land loss in the Mermentau Basin. In this report, we attempt to determine if there is a strong causal relationship between water level and historical land losses in the Louisiana Chenier Plain.

THE MERMENTAU BASIN

The Mermentau Basin of Southwest Louisiana can be divided into three sub-basins: Upland, Lakes, and Chenier (Figure 2). The Upland Sub-basin covers an area of 3,683 mi^2 of predominantly agricultural land. The Lakes Sub-basin is delineated by the Freshwater Bayou Canal on the east, the limit of the coastal zone on the north, Louisiana Highway 27 on the west, and Louisiana Highway 82 on the south. Highway 82 runs atop and between the Grand Chenier/Pecan Island ridge complex. The Chenier Sub-basin, which lies to the south of this ridge complex, consists mainly of the Rockefeller Wildlife Refuge and large areas of privately owned wetlands. Fresh and intermediate marshes dominate the Lakes and Chenier sub-basins (Table 1; Figure 3).

History of Hydrologic Alteration

We draw from USACE (1996) to describe the history of alterations made to the hydrology of the Mermentau Basin. Before human-induced hydrologic alterations from navigation channels in the early 1900s, the natural drainage in the Mermentau Basin was dominantly north-south through the Mermentau River, Freshwater Bayou, Bayou Lacassine, and Rollover Bayou. The eastern portion of the basin also drained in an easterly direction through Belle Isle and Schooner bayous (Figure 4). In addition, sheet flow over the marsh occurred between Grand Chenier and Pecan Island ridges, as well as to the west into the Calcasieu/Sabine Basin. Human activities related to wildlife management, navigation improvement, flood control, agriculture, and petrochemical exploitation have dramatically altered the hydrology of the Mermentau Basin. The net effect of these alterations is that drainage through the Lakes Sub-basin is now predominantly east-west and hydrologically isolated from the Chenier Sub-basin. The Lakes Sub-basin now functions more as a freshwater reservoir and less as a low-salinity estuary, its natural form (Gunter and Shell 1958; Morton 1973). We briefly discuss here the various alterations to Mermentau Basin hydrology, and detail them in Table 2.

Drainage Improvements, Navigation Projects, and Saltwater Intrusion Mitigation

Between 1915 and 1935, the upper Mermentau River and its four major tributaries were cleared, deepened, and somewhat straightened. These alterations facilitated the movement of rainwater and agricultural discharge from the Upland Sub-basin into the Lakes Sub-basin. The Mermentau River Project of the early 1950s enlarged the Mermentau River to a cross-sectional area of 3,000 ft^2 to better convey floodwaters to the Gulf of Mexico. In the 1970s, seven cutoffs were dredged on the upper Mermentau River between the communities of Lake Arthur and Mermentau, resulting in more rapid drainage into the Lakes Sub-basin following rain events.

Major federal navigation projects constructed include the Gulf Intracoastal Waterway (GIWW), the Inland Waterway (Old GIWW), and the Freshwater Bayou Canal and Lock. These three projects initially provided channels with cross sections ranging from 6 ft x 40 ft

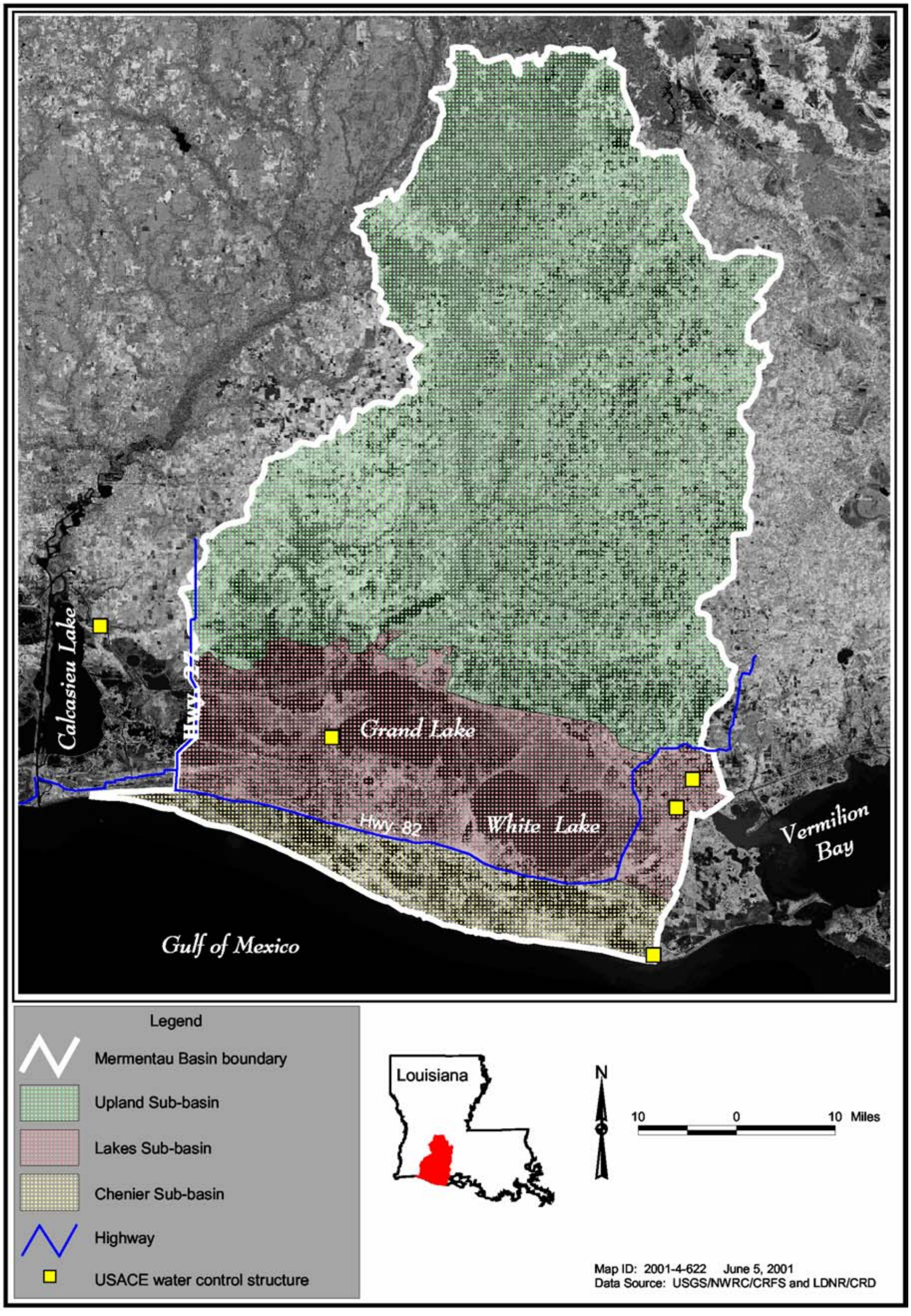


Figure 2. The Mermentau Basin.

Table 1. Wetland and aquatic habitat acreage in the Mermentau Lakes and Chenier sub-basins (after Chabreck and Linscombe 1997).

Habitat type	Acres	Percent of total cover (%)
Fresh marsh	319,098	44
Intermediate marsh	141,656	20
Brackish marsh	60,359	8
Salt marsh	25,090	3
Non-marsh/other	55,627	8
Water	120,537	17
Total =	722,367	100

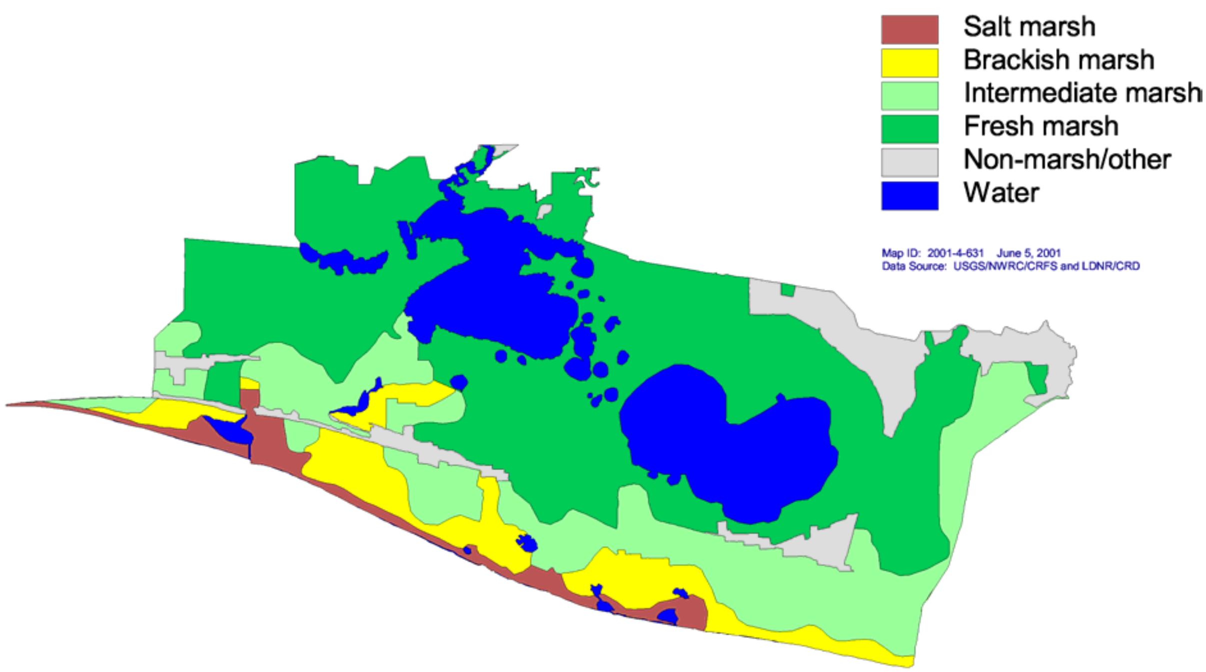


Figure 3. Wetland habitat types in the Mermentau Lakes and Chenier sub-basins (after Chabreck and Linscombe 1997).

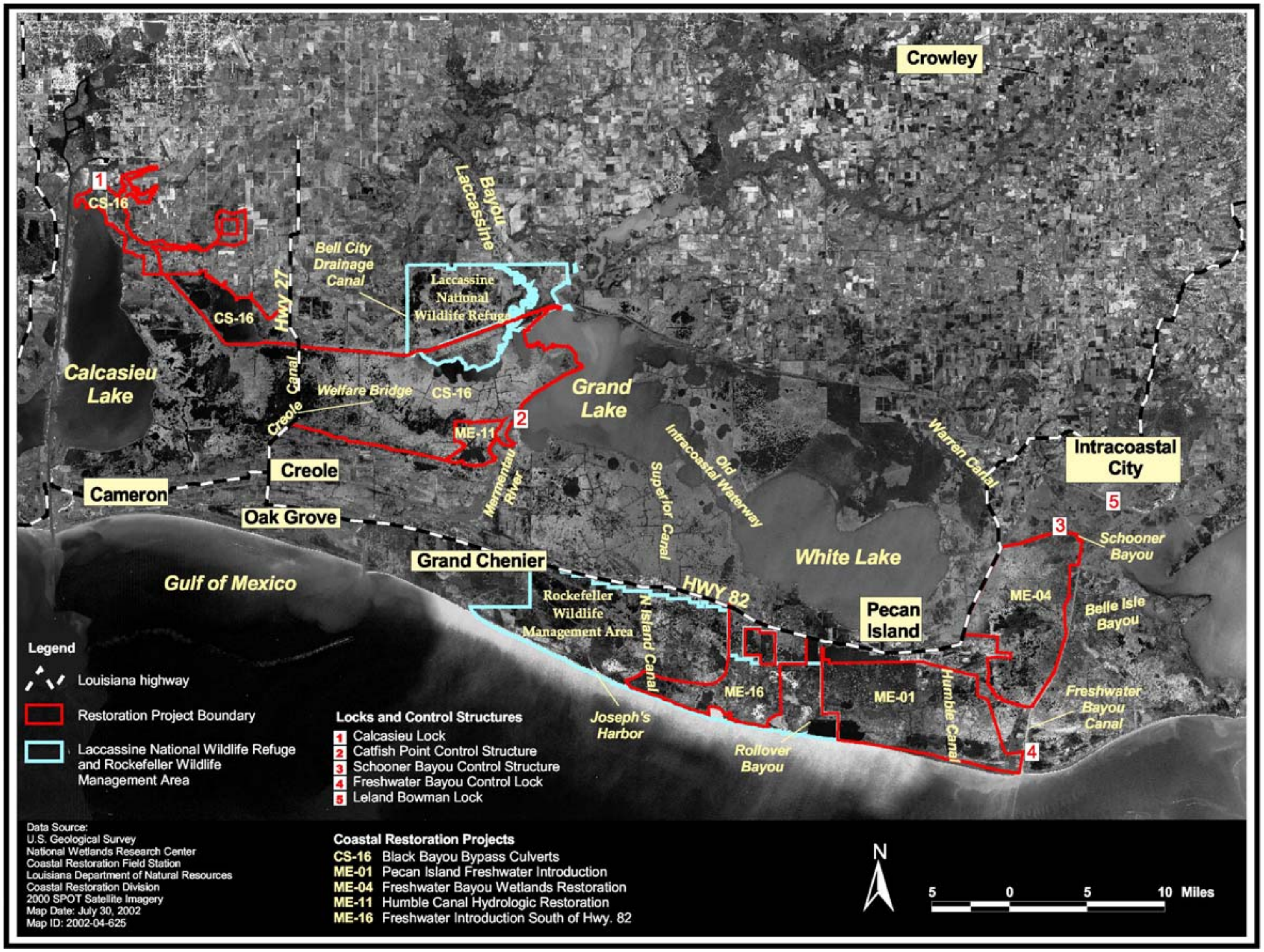


Figure 4. Physical features, locks and control structures, and restoration projects in the Mermentau Basin.

Table 2. Historical alterations to the hydrology of the Mermentau Basin.

Project name	Date completed	Project features
Inland Waterway (Old Intracoastal Waterway)	1912	5-ft deep by 40-ft wide channel through Schooner Bayou Cutoff, Schooner Bayou, new cut to White Lake, White Lake, Grand/White Lake Land Bridge, and Grand Lake to upper Mermentau River mouth.
Schooner Bayou Lock	1913	Small lock on Inland Waterway, later replaced by Schooner Bayou Control Structure.
Bayou Plaquemine Brule	1915	6-ft deep by 60-ft wide by 19-mi long channel from the mouth of the bayou to near Crowley. Recent straightening for flood control.
Bayou Queue de Tortue	1923	A. Dredge 10 cutoffs, remove obstructions in channel. B. Maintenance to 5 ft below Mean Low Gulf (MLG) initiated in 1969 (no commerce reported since 1955).
Gulf Intracoastal Waterway (GIWW)	1925-44	12-ft deep by 125-ft wide channel extending along the northern edge of the region from 2 mi west of the Vermilion River to the Calcasieu River.
Vermilion Lock	1933	11-ft deep by 56-ft wide by 1182-ft long lock, later replaced by Leland Bowman Lock.
Mermentau River and bayous Nezpique and Des Cannes	1935	A. Removal of obstructions from natural channels of Mermentau River from head to Gulf, lower 25 mi of Bayou Nezpique, and lower 8.5 mi of Bayou Des Cannes. B. Improvement of channel in Lower Mud Lake and construction of brush dam to concentrate current. C. Maintenance of a 9-ft deep by 100-ft wide channel between GIWW and bayous Nezpique and Des Cannes.
Louisiana Highway 27	1936	14 mi of secondary road running from Creole to 5.4 mi north of the GIWW.
Waterway from White Lake to Pecan Island	1939	Partially completed 5-ft deep by 40-ft wide channel from deep water in White Lake toward Pecan Island. (Later incorporated into Pecan Island Diversion for access to White Lake.)
Calcasieu Lock	1950	13-ft deep by 75-ft wide by 1194-ft long lock.
Catfish Point Control Structure	1951	Three sets of sector gates: two are 15 ft by 56 ft, one is 10 ft by 56 ft.
Schooner Bayou Control Structure	1951	Two sets of sector gates, each 12 ft by 75 ft. Replacement for Schooner Bayou Lock.
Mermentau River	1952	A. Channel improvement along the lower Mermentau River and Inland Waterway to provide 3000 ft^2 channel below MLG for flood drainage (supersedes portion of Mermentau River and bayous Nezpique and Des Cannes project). B. Construction of Catfish Point and Schooner Bayou control structures. C. Enlargement of Schooner Bayou Cutoff, North Prong, and Schooner Bayou to 6 ft deep by 60 ft wide to enhance navigation. D. Incorporation of waterway from White Lake to Pecan Island and Inland Waterway.
Louisiana Highway 82	1958	A. 32 mi of secondary road running from Pecan Island to Grand Chenier. B. 32 culverts and 12 bridges installed to facilitate drainage.
Freshwater Bayou Canal and Lock	1968	A. 12-ft deep by 125-ft wide channel from the GIWW to the gulf, following the Schooner Bayou Cutoff, Schooner Bayou, Six Mile Canal, Belle Isle Canal, and Freshwater Bayou. B. 16-ft deep by 84-ft wide by 600-ft long lock in the vicinity of Beef Ridge.
Mermentau River, Gulf of Mexico Navigation Channel	1971	A. 4.6-mi channel (15 ft deep by 200 ft wide) from point of entry of Lower Mermentau River into lower Mud Lake to the gulf. B. Dredge spoil used to create marsh in the vicinity of Lower Mud Lake. C. Built by Cameron Parish, maintenance assumed by USACE in 1976.
Modification of Mermentau River and bayous Nezpique and Des Cannes Project	1974, 1977	Construction of seven cutoffs 12 ft deep by 125 ft wide on the upper Mermentau River.
Leland Bowman Lock	1985	Replacement of Vermillion Lock with a larger (15 ft deep by 110 ft wide by 1200 ft long) structure.

to 12 ft x 125 ft. Over time, wake erosion has progressively widened these channels, and the spoil banks have breached, allowing saltwater intrusion into previously fresh areas. This intrusion compromises the freshwater reservoir relied upon by the region's rice farmers. The three locks and two sector-gated control structures surrounding the Lakes Sub-basin were built mainly to mitigate this saltwater intrusion. Recently, bank stabilization projects on the GIWW and Freshwater Bayou Canal have been constructed through the Coastal Wetlands, Planning, Protection, and Restoration Act (CWPPRA) program. The Mermentau River Gulf of Mexico Navigation Channel was constructed in 1971 by the East Cameron Port, Harbor and Terminal District. It is a 4.6-mi channel beginning where the Mermentau River enters Lower Mud Lake and extending south to the Gulf of Mexico. The U.S. Army Corps of Engineers assumed maintenance in 1976. In addition, the lower Mermentau River and Inland Waterway system were expanded to 3,000 ft^2 in cross section to facilitate flood drainage in the early 1950s.

Prior to navigation activities, the Mermentau River, like other rivers in the region, had a shallow mouth bar that limited tidal prism and saltwater intrusion. In 1971, Cameron Parish dredged the Mermentau River to Gulf of Mexico Navigation Channel to shorten and straighten the passage through Lower Mud Lake. This resulted in the gradual sedimentation of the lower Mermentau River below its entry into the lake. The natural channel southeast of the Creole Canal is now closed off. The Mermentau River to Gulf of Mexico Navigation Channel has continued to widen beyond its authorized dimensions, allowing more saltwater to intrude along a more direct path up the lower Mermentau River, Hog Bayou, and Little Pecan Bayou.

Lastly, the White Lake to Pecan Island Waterway (Mail Canal) was dredged in 1939 to facilitate commerce for the area. This small canal had no impact on drainage until it was incorporated into the state-funded Pecan Island Freshwater Introduction in 1992 (Figure 4).

USACE Water Control Structures

Because of the importance of the five water control structures installed by the U.S. Army Corps of Engineers (USACE) in the Mermentau Basin (Figure 4), we describe them in detail. Four of the structures, the Catfish Point and Schooner Bayou control structures and the Calcasieu and Leland-Bowman locks, directly regulate water levels and saltwater intrusion at the boundaries of the Lakes Sub-basin. The Freshwater Bayou Canal Lock is more removed from the Lakes Sub-basin, and aside from moderating saltwater intrusion from the Gulf of Mexico, may have a greater influence on water levels in the eastern Chenier Sub-basin than in the Lakes Sub-basin.

The Calcasieu Lock, built in 1950, is a 13 ft x 75 ft x 1194 ft navigation lock with a single set of sector gates on each end. Freshwater is drained from the Lakes Sub-basin via the GIWW, and studies have indicated that this long delivery channel limits the drainage opportunity at the Calcasieu Lock (USACE 1996). The lock was built to limit saltwater intrusion from Calcasieu Lake, a problem made worse by the deepening of the Calcasieu Ship Channel in 1940-43. The Calcasieu Lock currently operates as follows: when the water level inside the lock is above 2.0 ft Mean Low Gulf (MLG) and a sufficient head differential exists to allow water to drain from the Lakes Sub-basin into Calcasieu Lake, the structure is opened for drainage. If the inside water level is between 2.0 and 2.5 ft MLG, the lock master will still lock traffic through, but if the inside water level exceeds 2.5 ft MLG., the structure remains open when a sufficient head differential exists. The Calcasieu Lock is operated 24 hours a day.

The Catfish Point Control Structure, built in 1951, consists of three sets of sector gates aligned across the Mermentau River Channel (Figure 4). The sill depth of two of the 56-ft wide bays is at -15 ft MLG, while the third bay has a depth of -10 ft MLG. Installation of this structure reduced freshwater inflow from the Mermentau River, which resulted in the Chenier Sub-basin becoming a more tide-dominated estuary. A USACE study (USACE 1996) predicted that the structure would be able to move more water out of the Lakes Sub-basin, but the size of the receiving channel limits drainage potential. Current operating schedules at the Catfish Point Control Structure depend on various physical and ecological criteria. When the interior stage is greater than 2 ft MLG and greater than the outside stage, the structure is open for drainage. When the outside water level exceeds the interior stage by less than a foot, and the salinities in the basin are less than 26 grains/gallon (0.5 ppt) between Hackberry Point and Betty Lake, a 1-ft opening is left in the gates to allow for marine organism passage. For all other conditions, the structure is closed. Under extreme salinity conditions, locking of vessels may be either restricted or discontinued. The Catfish Point Control Structure is operated from 6:00 a.m. to 8:00 p.m. daily.

The Schooner Bayou Control Structure was built in 1951 to replace the Schooner Bayou Lock (Figure 4). It has two sector-gated bays, each 75 ft wide with a sill depth of -12 ft MLG, that stretch across the channel. When this structure was opened, the old lock channel was plugged. When the interior stage is greater than 2 ft MLG and greater than the outside stage, the structure is open for drainage. For all other conditions, the structure is closed. Under extreme salinity conditions, locking of vessels may be either restricted or discontinued. The Schooner Bayou Control Structure is operated from 6:00 a.m. to 8:00 p.m. daily.

The Freshwater Bayou Canal Lock was built in 1968 to control the intrusion of saltwater up the Freshwater Bayou Canal (Figure 4). This structure is 84 ft wide and 600 ft long, with a sill depth of -16 ft MLG. Anecdotal evidence from residents in the area suggests that the Freshwater Bayou lock may act to hold storm-surge water in the South Pecan Island area, which contributes to saltwater intrusion and marsh loss in this area. The lock remains open for drainage when the inside water level exceeds both 2 ft MLG and outside water levels. This lock is operated on a 24-hour basis.

The Leland Bowman Lock was built in 1985 to replace the old Vermilion Lock that was built in 1933 (Figure 4). The structure is 110 ft wide and 1,200 ft long, with a sill depth of -15 ft MLG The old lock channel was plugged rather than maintained for added drainage in response to concerns that the cross currents would present a hazard to navigation. This structure is operated 24 hours a day to drain water when the inside water level exceeds both 2 ft MLG and the outside water level, and when saltwater intrusion is not a problem. When a potential for saltwater intrusion exists, however, the structure is only operated to pass boat traffic.

Irrigation Improvements

The Bell City Drainage Canal and the Warren Canal (Figure 4) were dredged to supply freshwater from the Lakes Sub-basin to rice farmers in the Upland Sub-basin. These canals still function in this capacity, but they also convey floodwaters to the Lakes Sub-basin after storm passage. The Warren Canal has become a periodic avenue for saltwater intrusion, which is detrimental to rice culture. Because these canals are mainly used by rice farmers for surface water irrigation, agricultural runoff contributes to turbidity problems in Grand and White lakes. Recent improvements in rice varieties and implementation of water quality best management practices (BMPs) have reduced the negative effect of rice culture on receiving waters.

Highway Construction

Two state highways disrupt historical drainage patterns in the Mermentau Basin: Highway 82 from Abbeville, from northeast of the Lakes Sub-basin to Cameron, which was completed in 1958; and Highway 27 from Gibbstown, from north of the Lakes Sub-basin to Creole, which was completed in 1936. Louisiana Highway 82 runs from Abbeville to Cameron primarily through agricultural land, and drainage is fairly unobstructed through the Warren Canal, Inland Waterway, GIWW, and Freshwater Bayou Canal (Figure 4). After initial construction of Highway 82, landowner concerns about obstruction of drainage led the Louisiana Department of Transportation to install a system of 32 culverts and 12 bridges on Highway 82 from Little Pecan to the tip of Grand Chenier Ridge. Unfortunately, this system does not have the capacity to effectively drain the Lakes Sub-basin. A visual survey of all of the culverts running beneath Highway 82 revealed that most of the culverts and canals have silted in or have collapsed and become nonfunctional. North of Little Chenier Ridge, the only hydrologic connections across Highway 27 are beneath the Welfare Bridge and the Gibbstown Bridge (Figure 4). Also on Highway 27 between Grand Chenier and Little Chenier ridges, there are five 4-ft flapgated culverts that allow drainage to the west into the Creole Canal.

Wildlife Habitat Management

The Lacassine National Wildlife Refuge (NWR; Figure 4), completed in 1943, contains a large (16,000 acre) impoundment built to enhance waterfowl resting and nesting habitat. The input of water for the impoundment comes entirely from rainfall, and the pool is drained through three control structures into Bell City Drainage Canal and Bayou Lacassine. Management plans state that the water is drawn down to 3.5 ft Mean Sea Level (MSL) during 15 October-15 January, when stop logs are placed to allow the pool to fill to 5 ft MSL. This enhances fishing and opens up areas of the marsh for desirable plant species. The management objectives are to have the pool provide loafing area for migratory waterfowl, while adjacent areas (some of which are planted) support feeding. The submerged aquatics within the pool and the accompanying invertebrates provide excellent food sources for diving ducks, grebes, and other species. Maidencane (*Panicum hemitomon*) and bulltongue (*Sagittaria lancifolia*) are the dominant emergent plants, but they have little food value for waterfowl. Refuge officials observe that, while waterfowl do utilize the area as a stopover, they usually leave the pool to feed.

The Rockefeller Wildlife Refuge (Figure 4) is a state-owned refuge encompassing 119 mi^2. Much of this area is leveed and managed for waterfowl and fishery habitat. The constructed levees have greatly moderated salinity and water level fluctuations, and the management plan is deemed successful in meeting refuge objectives. The primary objective in the creation of this refuge was to promote scientific research. This has been accomplished through a wide variety of studies, including world-renowned research on the American alligator (*Alligator mississippiensis*).

Several private landowners (Miami Corporation, Vermilion Corporation, Amoco Corporation, and the M. O. Miller estate) also have implemented marsh management plans, typically to enhance waterfowl habitat or wetlands. The M.O. Miller estate was managed primarily for cattle until the death of Dr. M.O. Miller. Since then the emphasis has been placed more on oil production, and maintenance of levees and structures has declined. These private projects are monitored only sporadically, so no assessment can be made of the success or failure of their management plans. Effects of these efforts vary according to the perspective of the assessor, but it is obvious that, like those in the Lacassine NWR and Rockefeller Wildlife Refuge, these projects have modified wetland hydrology by improving vegetative and wildlife community structure in the affected areas.

Access Canals for the Oil and Gas Industry

Several large access canal systems were constructed in the Mermentau Basin to allow exploitation of oil and gas resources. Among the largest are the Superior Canal and North Island Canal systems between the Lakes and Chenier sub-basins, and the Humble Canal in the eastern portion of the Chenier Sub-basin (Figure 4). All of these canals have facilitated saltwater intrusion into brackish and intermediate marshes and have been cited as a major cause of land loss. Structural management has resulted in the Superior and North Island canal systems no longer being avenues for extreme saltwater inflow. Trenasses, or smaller canals used by the fur trapping industry, have had similar environmental effects. For example, the Louisiana Fur Canal appears to have functioned in combination with Rollover Bayou (a natural stream) and the Humble Canal (an artificial channel) to facilitate saltwater intrusion into the South Pecan Island area, which contributes to deterioration of marshes in the vicinity.

Hydrologic Restoration and Protection Projects Funded by the State and Federal Governments

The Pecan Island Freshwater Introduction

The Pecan Island Introduction, a canal that extends from the Mail Canal to Louisiana Highway 82 (ME-01 on Figure 4), was built in 1992 as one of the first state-only projects to address both perceived excessive flooding in the Lakes Sub-basin and excessive saltwater intrusion in the South Pecan Island area. The essential structures making up the Pecan Island project include three 4-ft culverts controlled by screw gates that regulate flows under the highway. This improvement was designed to work in conjunction with control structures already in place on Rollover Bayou and the Louisiana Fur Canal. Although monitoring on this project has now been terminated, early results indicated that the project effectively reduced salinity levels in the southern project area, especially during the months of November through April. However, data indicated that salinity spikes still occurred during times of extended southerly winds, showing a need for some form of outfall management.

Black Bayou Bypass Culverts Hydrologic Restoration

This project is located east of Calcasieu Lake, and includes areas north of the GIWW and south of Grand Lake above Louisiana Highway 82 (CS-16 on Figure 4). The goal of this project is to relieve perceived stresses on marsh vegetation caused by prolonged flooding. Proposed project components include installing ten 10-ft by 10-ft concrete box culverts with sluice gates in Black Bayou, and relocating Highway 384 over the culverts. Operation of the structure will be in coordination with Calcasieu Lock and the Schooner Bayou and Catfish Point water control structures. This project is in the planning stage and is under review to determine the validity of its goals and likelihood of success in achieving them.

Humble Canal Hydrologic Restoration

The Humble Canal Hydrologic Restoration Project (ME-11 on Figure 4) encompasses 4,030 acres located near the southwestern side of Grand Lake. The project is bounded by the Little Chenier Ridge to the south, the Mermentau River to the east, oilfield canals on the west, and an east-west trenasse and an oilfield canal along the north. The marsh is classified as a fresh marsh with 74% of the project area being marsh and 26% open water. The goal of the project is to remove excess water without permitting saline water into the freshwater marsh of the project area. Project features include three 48-in culverts with variable-crest weir inlets and flapgated outlets in an oilfield access canal north of Marseillaise Bayou and enlargement of a conveyance channel between the culvert structure and Humble Canal. This project is expected to be constructed by the end of 2002.

Freshwater Introduction South of Highway 82

The purpose of this project is to alleviate saltwater intrusion south of Grand Chenier by introducing freshwater across Highway 82 into Rockefeller Wildlife Refuge (ME-16 on Figure 4). Increasing freshwater access under the highway into Rockefeller Wildlife Refuge is expected to reduce marsh in the Chenier Sub-basin and restore a more natural hydrology. Currently, water flow south of the highway is retarded by the dilapidation and/or lack of adequate structures to allow flow across the chenier. This project proposes the addition and removal of some structures within the refuge to remedy this problem. It is currently in the planning stage.

Freshwater Bayou Wetlands

The Freshwater Bayou Wetlands project (ME-04 on Figure 4) encompasses approximately 37,000 acres of fresh to intermediate wetlands located between Louisiana Highway 82 and Freshwater Bayou Canal, approximately 5 mi east of White Lake, Louisiana. Boat wake-induced shoreline erosion, which averaged 12.5 ft/yr along each bank of Freshwater Bayou Canal between 1968 and 1992, has deteriorated the spoil banks along the channel, creating multiple breaches that allow tidal scour of the organic soils in the adjacent wetlands. Between 1968 and 1990, the bank width of this navigation canal increased threefold from 172 ft to 583 ft, resulting in the loss of 1,124 acres of coastal wetlands due to bank erosion. Phase 1 of this project was constructed in 1996.

The objective of Phase 1 of this project was to prevent further widening of the Freshwater Bayou Canal channel into the project area, thereby protecting existing emergent wetlands along the west bank of the canal from further deterioration caused by shoreline erosion and tidal scour. The specific goal of the project is to decrease the rate of erosion and wetland loss along the west bank of Freshwater Bayou Canal by using a rock dike. Construction of approximately 28,000 linear ft of free-standing, continuous rock dike along the west bank of the canal was completed in January 1995.

As presently planned, the remaining restoration efforts being implemented under Phase 2 of this project will involve the installation, operation, and maintenance of eight water control structures in an effort to reduce ponding and increase the acreage of emergent marsh in the interior of the project area. The Phase 2 project plan is to lower water levels or reduce the frequency and duration of marsh inundation in the project area, in an effort to manage water levels to mimic natural conditions. Salinity will be maintained at low levels suitable for the growth of fresh to intermediate marsh. These goals will be accomplished through active and passive management of water control structures. The volume of water flowing into the project area from the west through canals and other channels will be reduced by installing plugs and gated culverts that will restrict channel flow and promote sheet flow over the marsh surface. In addition, the discharge capacity from the central and southern sections of the project area will be increased by installing additional variable-crest water control structures.

Management Issues in the Lakes Sub-basin

Management issues in the Lakes Sub-basin are interrelated in a complex manner. The main objective of the USACE is to maintain the freshwater reservoir in this sub-basin for agriculture, but operational guidelines do allow for operation of the control structures to maintain sufficient water levels for navigation. Thus, the reservoir is operated for the dual purposes of agriculture and navigation. However, these objectives hinder access of estuarine organisms due to the semi-impounded nature of the basin, and agricultural runoff exacerbates turbidity problems in the lakes. Rice has a very low tolerance to salt and, with the current emphasis placed on avoiding the use of groundwater, the need for low-salinity surface water has become more important. A comprehensive management plan that maintains the freshwater reservoir while allowing for estuarine organism access has been difficult to create, but some progress has been made through a series of meetings planned to engage all concerned parties, such as local navigation and agriculture groups, and fishing interests.

Maintaining a Freshwater Reservoir

The five locks and control structures surrounding the Lakes Sub-basin were constructed primarily to control saltwater intrusion into the freshwater reservoir and maintain a sufficient water level for navigation. The control structures would not have been necessary were it not for construction of the GIWW, the Inland Waterway, and the Freshwater Bayou Canal, and the expansion of the lower Mermentau River.

The goals of controlling salinity and maintaining water levels for navigation are themselves mutually exclusive under certain conditions. As little as 0.55 ppt of salt can kill rice crops, eventually triggering substantial economic losses (Hill 2001). Saltwater can intrude through the GIWW, Freshwater Bayou Canal, Mermentau River, and the Inland Waterway system. Saltwater intrusion occurs in times of drought, when locking operations allow spikes of saltwater into the sub-basin and insufficient head differential exists to flush the saltwater out. The problem is exacerbated by the locations of irrigation canals and pumps. The Warren Canal extends to the Inland Waterway near the Schooner Bayou Control Structure. When basin water levels fall below -0.8 ft MLG, the Schooner Bayou Control Structure is operated to draw water from the GIWW-Freshwater Bayou Canal System to maintain sufficient elevation for navigation. This allows water from the Gulf of Mexico and brackish water from Vermilion Bay to enter the system.

Providing Access for Estuarine Organisms

The historical oligohaline estuary of the Mermentau Basin has been substantially converted to the current freshwater reservoir (Gunter and Shell 1958; Morton 1973). Significant shrimp and crab fisheries do still exist, however, whose viability depends upon operations of locks and water control structures. When structures are closed, established organism access routes are closed and shrimp and crab landings fall. During years when high navigation traffic is reported through the structures, fishermen report excellent harvests.

Current USACE operational schedules provide for a 1-ft opening for estuarine organism access at the Catfish Point and Schooner Bayou control structures when this opening does not conflict with water level management and does not cause significant saltwater intrusion.

Reducing Turbidity in Grand and White Lakes

Increased turbidity in Grand and White lakes resulting from agricultural runoff reduces the habitat quality for submerged aquatic vegetation and for the fishery species that depend on it. Freshwater and estuarine species are all affected by this water quality problem. One potential option for reducing turbidity is to allow limited amounts of saltwater into Grand Lake at the Catfish Point Control Structure. This approach would help to flocculate some of the sediment and clear the water in limited portions of the system (Day et al. 1989), but it potentially runs counter to the agricultural objective of maintaining the freshwater reservoir. The Louisiana Cooperative Extension Service is currently working with Mermentau Basin rice farmers to institute a series of best management practices (BMPs) to reduce sediment runoff into the system, and the NRCS has cost-share programs available to basin farmers for aiding installation of BMPs. These BMPs mainly focus on allowing sediment to settle out in the rice fields before farmers drain the floodwater from the fields. If these BMPs are successful in reducing turbidity, fisheries habitat could be enhanced without allowing more salt into the system.

Moderating Water Levels from Storm Flooding

Some area residents feel that the USACE water control structures in the Lakes Sub-basin hold water levels too high. Upland drainage improvements may have decreased retention time in the Upland Sub-basin and exacerbated flooding in the Lakes Sub-basin, while downstream water control efforts restrict the drainage potential and lead to more frequent flooding. Four regional ecosystem strategies from the Coast 2050 plan directly address this issue (LCWCRTF/WRCA 1998).

Mermentau Basin Hydrologic Analyses

Data Sources

No new hydrologic data were collected for this study. Water level, salinity, river discharge, and weather data were acquired from various federal and state agencies, as outlined below. We contracted with John Chance Associates, Inc. of Lafayette, Louisiana, and On Target Surveying, Inc., of Grand Chenier, Louisiana, to use global positioning system (GPS) technology to conduct marsh elevation surveys for selected areas.

Water level data were acquired from the USACE New Orleans District. Daily water level is recorded by lock and control structure operators from gauges attached to the structures, both inside and outside of the Lakes Sub-basin. Two data collection platforms, installed one on either end of each structure, record hourly water level data (Figure 4). The data record described here covers a 14-yr period, 1987-2000. The hourly stage data were adjusted from the Mean Low Gulf (MLG) datum to the North American Vertical Datum 1988 (NAVD-88).

Additional hourly water level data were acquired from the CWPPRA-funded monitoring of the Highway 384 Hydrologic Restoration Project. This 28-month record extends from May 1997 to August 1999.

Daily river discharge data for the Mermentau River at Mermentau and Bayou Lacassine near Lake Arthur were obtained from the United States Geological Survey (USGS), Water Resources Branch, Baton Rouge office. These data are not continuous and many gaps exist. Where possible, discharge data lacking for Bayou Lacassine were modeled from Mermentau River discharge, and vice versa. This still left several gaps in the data that could not be filled. Because of the low flow of the two streams and the seasonal reverse flow, no suitable surrogate within the USGS freshwater discharge gauging system is available for use in modeling the data gaps.

We utilized salinity data collected by the USACE in conjunction with their normal structure operations. Salinity is monitored daily both inside and outside of the control structures, and stations that are farther away from the structures are monitored if the readings indicate the potential for saltwater intrusion. Data from the outlying stations were unavailable.

Weather data were acquired from two sources, the USACE and the Louisiana Office of State Climatology (LOSC). The USACE data consists of monthly records prior to 1995 and daily data for 1995-98 from the five Mermentau Basin structures, Hackberry, and the Mermentau River at Grand Chenier. The LOSC provided daily data, such as wind speed and direction, collected at the Lake Charles Municipal Airport station. Monthly data from the LOSC station were obtained from the National Climate Data Center web page, which also provided data that filled several gaps in the Hackberry station data set.

Data Analyses and Results

Long-Term Water Level

Before analyzing water level data, we tried to distinguish the magnitude and effect of gauge subsidence on the water level record. Linear regressions were performed on the monthly averages for the inside and outside gauges at all five USACE water control structures. Data from a 1996 survey of gauge elevations were used to calculate subsidence at gauges since their placement, assuming that the gauges were placed properly when installed and had not been corrupted during normal maintenance operations (USACE 1996). From our estimate (Table 3), the rate of subsidence from the Catfish Point Control Structure accounts for 75.8% of the rise rate inside and 47.6% of the rise rate outside of the structure. These percentages are markedly higher than those of the other structures, and the subsidence rate

Table 3. Rates of water level rise at the USACE control structures in the Mermentau Basin.

Control structure	**Subsidence[a] (in/yr)**	**Inside rise rate[b] (in/yr)**	**Residual[c] (in/yr)**	**Percent due to gauge subsidence (%)**	**Outside rise rate[b] (in/yr)**	**Residual[c] (in/yr)**	**Percent due to gauge subsidence (%)**
Calcasieu	0	0.15	0.15	0.00	0.27	0.27	0.00
Catfish Point	0.15	0.19	0.05	75.81	0.31	0.16	47.64
Leland Bowman	0	0.18	0.18	0.00	0.27	0.27	0.00
Schooner Bayou	0.02	0.17	0.15	9.56	0.29	0.27	5.65
Freshwater Bayou	0.06	0.28	0.22	22.73	0.31	0.25	20.43

a- Calculated from data in USACE 1996.
b- Linear regression on monthly average water level.
c- Percent of rise rate due to subsidence.

appears to be overestimated by 0.08-0.11 in/yr. This overestimate is probably attributable to improper installation of the gauge, either at construction or during replacement of the gauges over time. In any case, based on the residual rates of rise outside of the four control structures directly bordering the Lakes Sub-basin, we suggest that a better estimate of subsidence at the Catfish Point Control Structure is 0.04 in/yr.

Water levels appear to be rising both inside and outside of all five water control structures, with the four structures located directly on the Lakes Sub-basin boundaries showing similar rates of relative sea level rise. After correcting for subsidence, the rate of water level rise within the Lakes Sub-basin impoundment is 0.16 ± 0.02 in/yr, while the rate of water level rise outside of these structures is 0.27 ± 0.02 in/yr. Water level records for the Freshwater Bayou Canal Lock indicate an overall rate of rise of 0.22 in/yr inside and 0.25 in/yr outside the structure, after correcting for gauge subsidence. Much of this difference between inside and outside rates of water level rise is likely due to management of the freshwater reservoir. In the early portion of the record, inside water levels were higher than outside levels to maintain a 2.0-ft MLG reservoir. This rate of rise is markedly different from the 0.84 in/yr rate referenced in Gosselink (1979) that was based on mean annual water levels between 1963 and 1974. Our calculation of the rate of rise used a regression based on mean annual water levels at all USACE structures over the period 1945-99. Water level appears to have risen faster during the period analyzed by Gosselink (1979) and has tapered off since that time. Later in the records, as the outside water levels rose, the inside target remained 2.0 ft MLG, so the lakes will be drained whenever possible to maintain lower water levels. For all structures, the rates of rise are within the range of vertical organic matter accretion reported for freshwater, intermediate, and brackish marsh communities in other parts of coastal Louisiana (Delaune et al. 1983; Hatton et al. 1983; Baumann et al. 1984; Knaus and Van Gent 1989; summarized in Table 4), so it seems likely that vertical accretion in this area would be sufficient to keep pace with the rate of relative sea level rise in the region. However, there appear to be cycles with a period of 5-10 years during which the water level rises much more rapidly and then falls just as quickly. This may be tied to similar cycles in annual rainfall (Figure 5). This leads to the hypothesis that there may be cyclical marsh loss and gain related to decadal changes in inundation duration and frequency, with long-term losses and gains controlled by the relative duration of these cycles.

Total yearly rainfall (averaged over the region) and average annual water level inside the five control structures are correlated (r^2=0.59). When water level is plotted against total annual rainfall (Figure 6), the scatter plot is best described as a power function: $WL=0.1008R^{0.7595}$ (r^2= 0.59; where WL= average annual water level in feet above MLG and R=total annual rainfall in inches). Other factors that may contribute to the variability include timing of rainfall (more rain in the winter months leads to higher water levels because of the decreased evapotranspiration and agricultural losses then), evenness of the rainfall (several continuous months with lower than normal rainfall lead to lower water levels regardless of time of year), and land use patterns.

USACE records indicate that the average head differential between the outside gauge of the Catfish Point Control Structure and the Grand Chenier Bridge significantly increased from 0.17 ft ± 0.54 ft to 0.44 ft ± 0.81 ft. This increase appears to be too large to be

Table 4. Summary of marsh accretion studies in the Mermentau Lakes Sub-basin.

Citation	Study area	Marsh type	Dominant plant species	Accretion rate (in/yr)	Notes
Delaune et al. 1983.	East Cove Marsh on the south side of Calcasieu Lake	Brackish	*Spartina patens*	0.3	Accretion rates were determined from five cores using ^{137}Cs dating and artificial marker horizons. This study was conducted in a low-salinity brackish marsh that is in close proximity to the Lakes Sub-basin.
Hatton et al. 1983.	Upper Barataria Basin just south from Lac Des Allemands	Fresh	*Panicum hemitomon, Sagittaria lancifolia, Eleocharis* sp.	0.26	Accretion rates were determined from 10 cores using ^{137}Cs dating.
Baumann et al. 1984.	Fourleague Bay	Intermediate	*Spartina patens*	0.26	Accretion rates were determined from 14 sites using ^{137}Cs dating. It is worth noting that this area receives mineral sediment input from the Atchafalaya River.
Knaus and Van Gent 1989.	Rockefeller Wildlife Refuge	Fresh to Brackish	Unknown	0.21 - 0.38	Artificial marker horizons were established using the stable rare-earth elements dysprosium and samarium over a 2-yr period. Samples were collected by cryogenic core, and accretion rates were determined by instrumental neutron activation analysis.
	Lac Des Allemands	Fresh	Unknown	0.47 - 1.8	

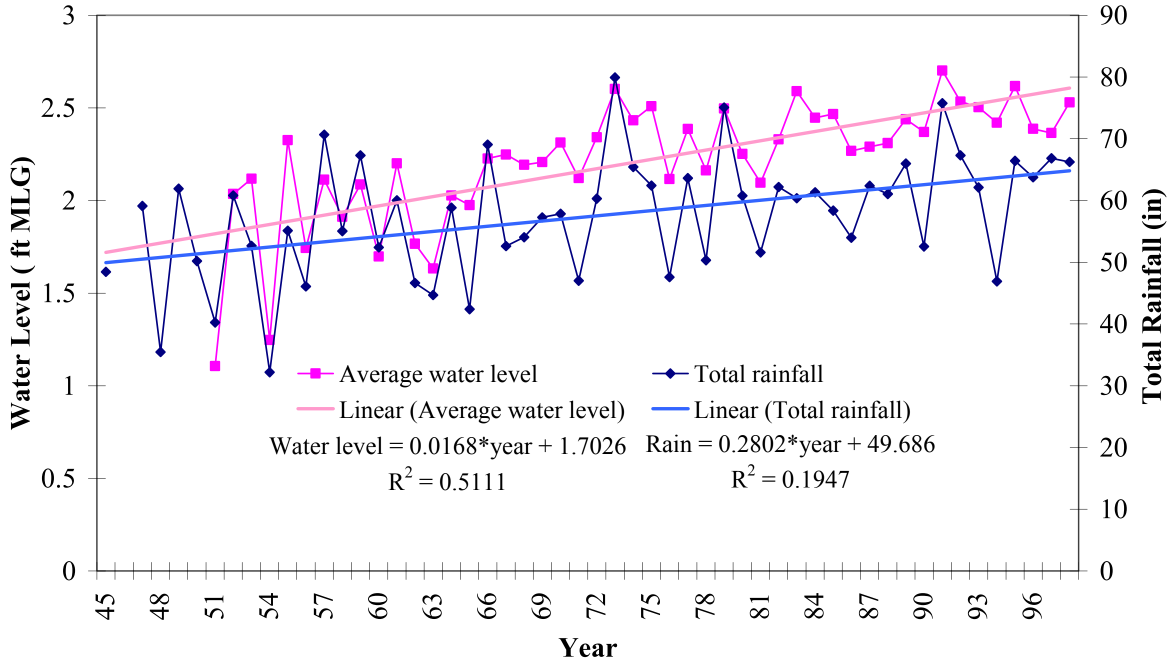


Figure 5. Total yearly rainfall and average annual water levels inside all USACE control structures in the Mermentau Lakes Sub-basin. Water level is based on daily 8 a.m. readings over the period of record.

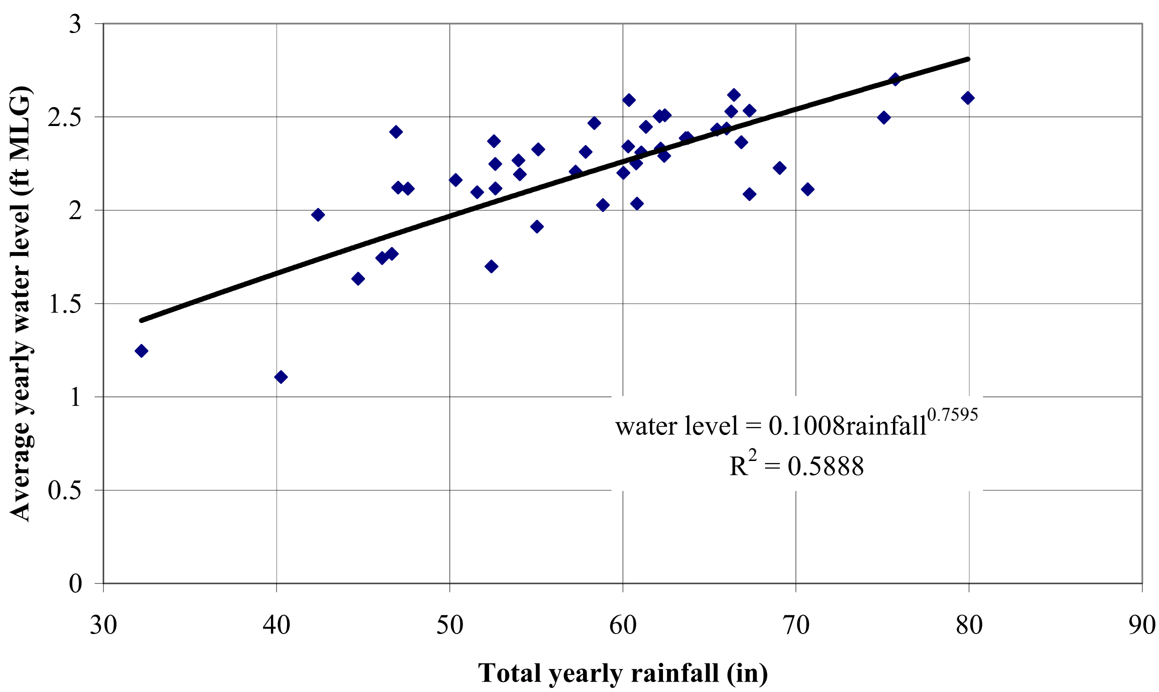


Figure 6. Relationship between water level and annual rainfall in the Mermentau Lakes Sub-basin. Water level is based on daily 8 a.m. readings over the period of record.

accounted for by differential subsidence, and we suggest that this rise is associated with dredging of the Mermentau River Cutoff and ship channel. Channelization may have established a more hydrologically efficient connection to the Gulf of Mexico and increased tidal amplitude. A greater tidal amplitude would result in the observed increase in head. Dredging of the channel also caused the silting in of the natural mouth of the Mermentau River and may have worsened saltwater intrusion into the upper Chenier Sub-basin marshes and between Oak Grove and Grand Chenier. This conclusion is speculative because salinity records do not extend far enough back in time to test this hypothesis. When the Catfish Point Control Structure is closed, the only supply of freshwater to the tidal western Chenier Sub-basin is local rainfall.

Rainfall and air temperature data over the long term seem to explain the bulk of the variability in water level. The number and timing of severe rainfall events can contribute to high water levels, while lower temperatures contribute to decreased losses by evapotranspiration. Examining the long-term records as presented in Muller and Grymes (1997), we observe three trends: 1) overall, rainfall has been increasing since the late 19th century; 2) since 1955, the number of severe weather events has been increasing, particularly in the winter and spring months; and, 3) temperatures since the 1960s have been lower than in the previous 40-60 years, with an increasing trend since the mid-1970s. These trends suggest that, without factoring in other influences, water levels should have increased in the 1960s, when there were more flooding events and decreased temperatures, and this increase should have been mitigated since the mid-1970s by increasing temperatures. This scenario matches anecdotal evidence provided by area residents and experts, and can be seen upon close examination of Figure 5. Annual water levels appear to rise substantially in the 1960s and level off somewhat in the 1970s and beyond.

Short-Term Water Level

Rainfall in the short term appears to be the factor that most explains water level fluctuations within the Lakes Sub-basin (Figure 7). Rainfall events typically have an immediate impact through direct input and a somewhat longer-term effect through upland drainage. Water levels outside water control structures appear to be dominated more by tides and wind, but when the structures are operated for drainage, the water level data from the outside gauge are corrupted because riverine influences become dominant over tidal influences (for example, see the passage of Tropical Storm Frances in September 1998; Figure 7). Although rainfall always increases the water level within the Lakes Sub-basin, the degree of increase is somewhat dictated by the time of year and temporal spacing of rainfall events. Large rainfall events in the winter and early spring months lead to greater water level increases because of decreased evapotranspiration losses and agricultural use.

Gosselink et al. (1979) demonstrated that the probability of a rain deficit (i.e., more water leaves the surface by evaporation than is added by rainfall) is significantly increased in the months of April-November, and this rainfall deficit is also reflected in the average monthly head differentials for the period 1987-2000 (Figure 8). On average, there is a greater drainage potential from the Lakes Sub-basin in the months of December-March, as

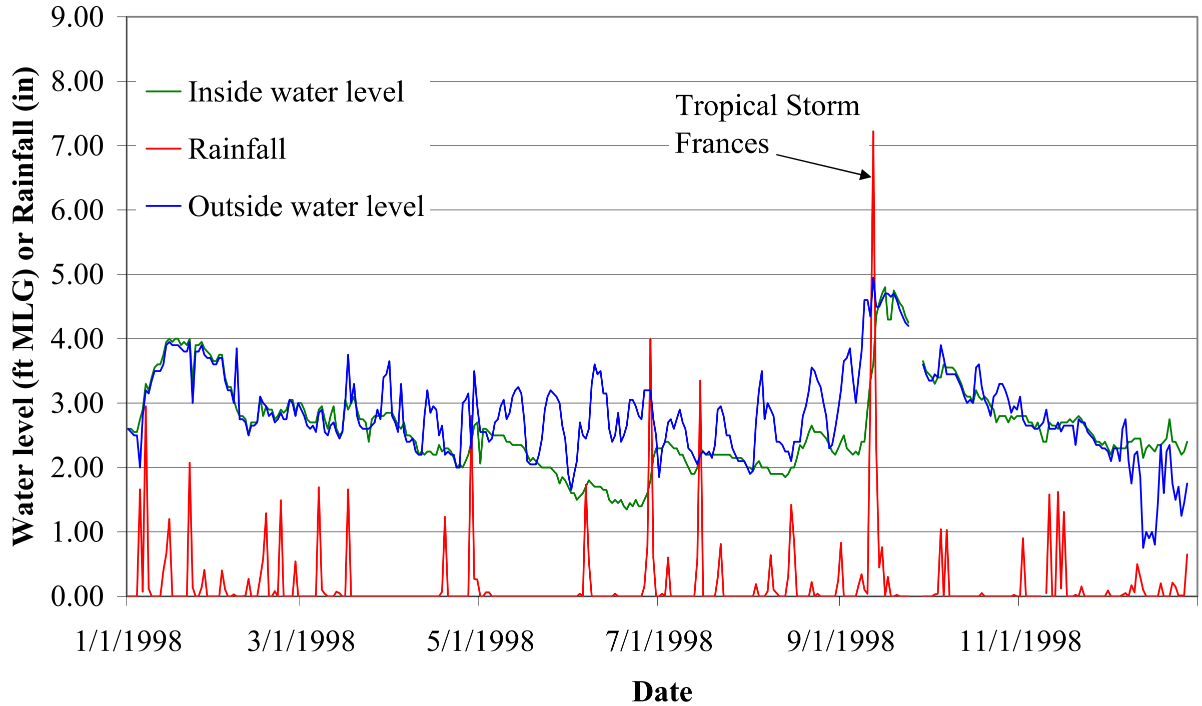


Figure 7. Water levels inside and outside the Catfish Point Control Structure in 1998. Water level is based on daily 8 a.m. readings.

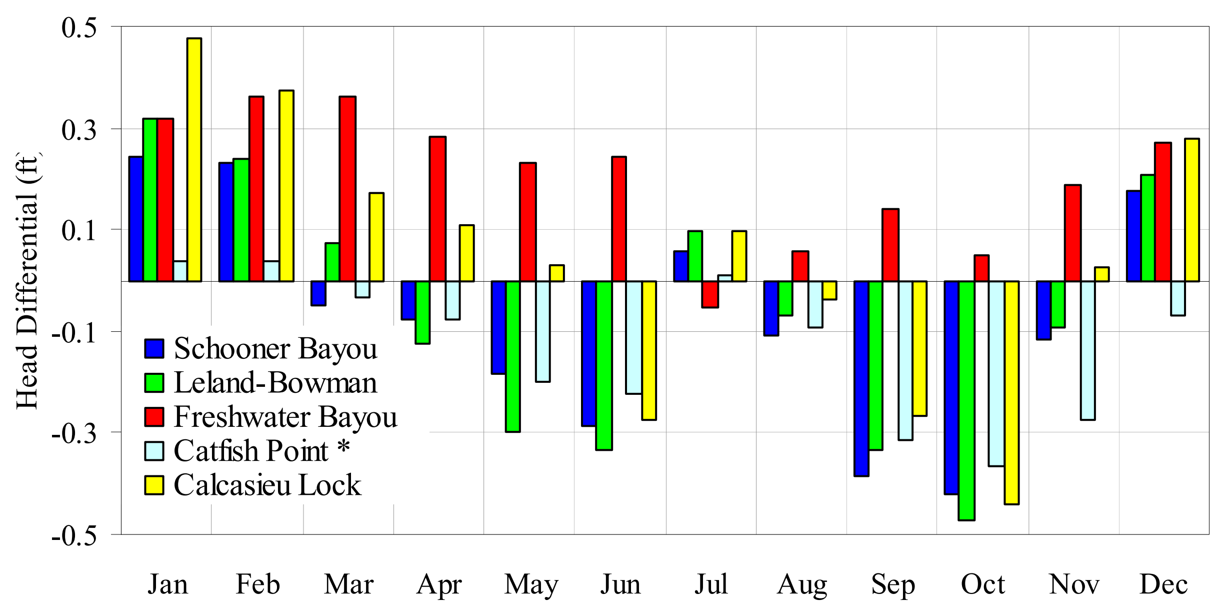


*Figure 8. Average monthly head differentials for the USACE water control structures, 1987-2000. *Catfish Point data from 1990-2000.*

evidenced by the larger head differential then. This lack of drainage potential in the summer and early fall months is probably not detrimental to flood prevention efforts, because Lakes Sub-basin water levels are lower at this time. In addition, because salinity becomes a greater problem during summer months, it is unlikely that the structures would be open a significant portion of the time then.

Salinity

We analyzed salinity records from the Schooner Bayou and Catfish Point control structures for the period 1 January 1995 - 31 December 1998. Within the Lakes Sub-basin impoundment, the month of measurement accounts for 54% and 42% of the measured variability at the Catfish Point Control Structure and Schooner Bayou Control Structure, respectively. This is probably due to the rainfall deficit and drainage potential described in the previous section. Salinity outside of the structures rises in April, increases to a September peak, then declines through December and into the following March (Figure 9). This pattern is mimicked inside of the structures, but the increases are somewhat muted. At the Catfish Point Control Structure, average outside salinities for the 4-yr period exceeded the 0.55-ppt threshold, where salinity begins to harm rice farming, in all months from May through December. At the Schooner Bayou Control Structure, this threshold was exceeded only during June and August-November. Because the Schooner Bayou Control Structure is particularly close to the rice fields and crawfish farms of Vermilion Parish, salinity spikes at this structure are probably detrimental to those industries throughout the year.

Marsh Elevation Data Collection

Static and Real Time Kinematic Global Positioning System (GPS) technology was employed to determine marsh elevation at 28 stations in the Mermentau Basin (Figure 10). We established a primary GPS monument network throughout the study area, and strategically selected secondary monument locations to record interior marsh elevations. Survey information from these stations was generated through this study and from two CWPPRA restoration projects (LDNR 2000a; LDNR 2000b). Approximately 3,000 marsh elevation measurements in 28 stations were collected in accordance with CWPPRA project monitoring protocol (Steyer et al. 1995). Sites in close proximity to the USACE water control structures were chosen for marsh flooding analysis based on the assumption that water level information collected at the structures reflects water level fluctuations in nearby hydrologically connected marshes.

Elevations of the marsh surface and the adjacent mudline were collected at the sites shown in Figure 10. We determined data collection points by establishing a survey "center point" in the marsh and collecting elevations along a circle with a 400-ft radius from that center point. Between 15 and 22 stops were made in regular increments around each circle, and at each stop we recorded the elevations of the organic mat, the top of the root mass, and the adjacent mudline. Average elevations and associated data sources for those points are listed in Table 5. The average marsh elevation was approximately 1.19 ft NAVD-88, with

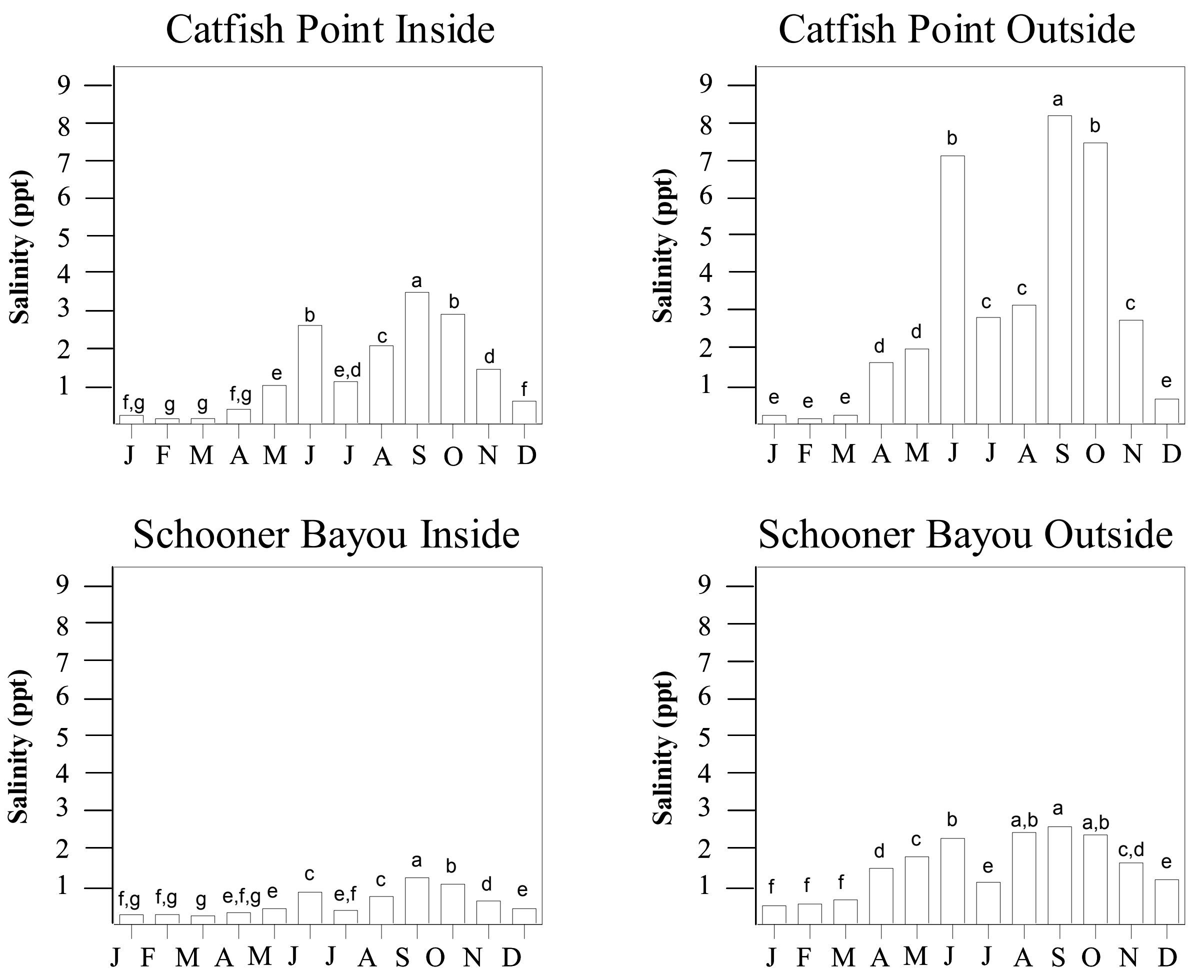


Figure 9. Average monthly salinity inside and outside of the USACE Catfish Point and Schooner Bayou control structures during the period 1995-98. Bars sharing common letters are not significantly different.

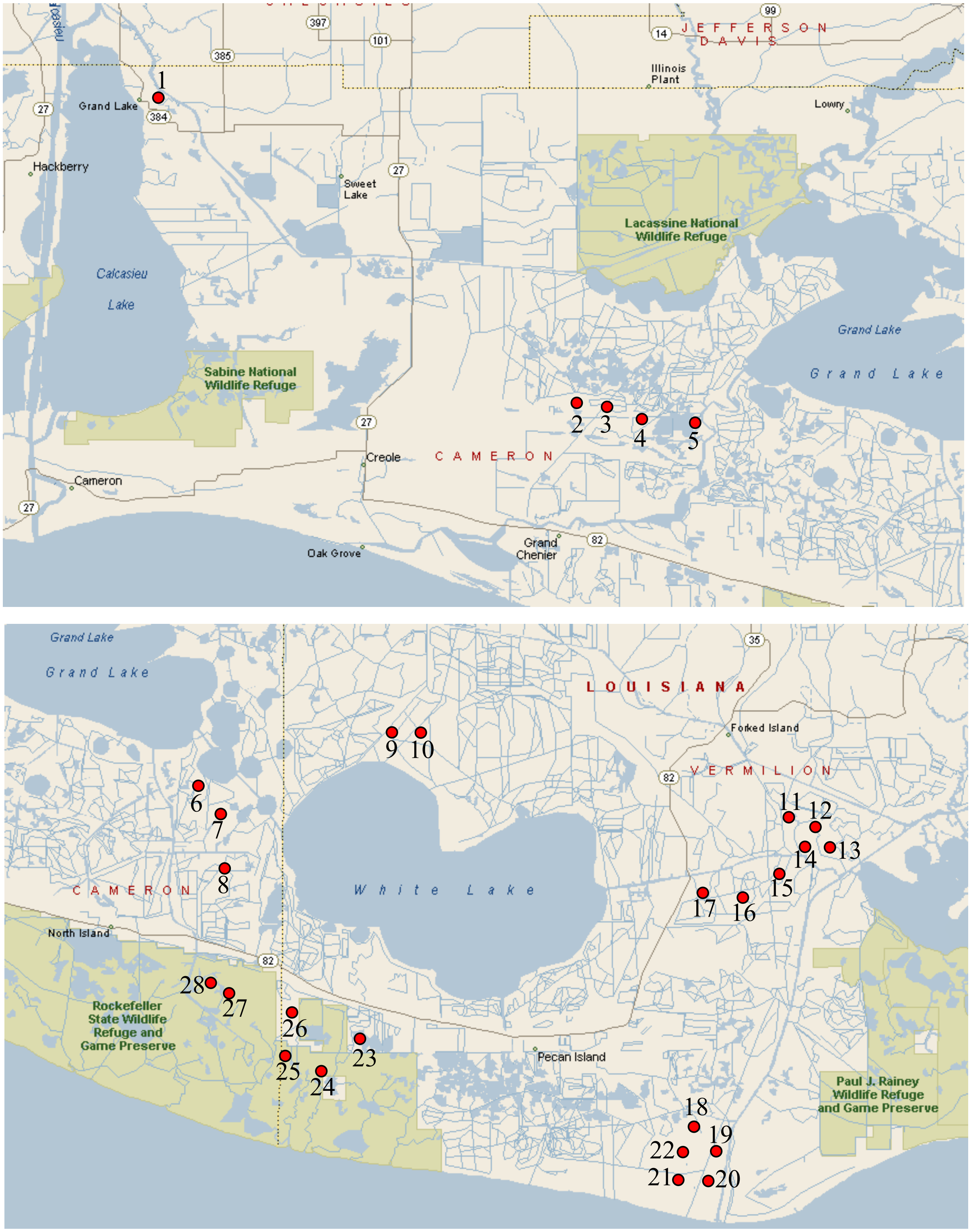


Figure 10. Marsh elevation survey sites in the Mermentau Basin.

Table 5. Marsh elevations in the Mermentau Basin.

Map site	Mean mud line elevation (ft, NAVD-88)	Standard deviation (ft)	Mean root mass/organic mat elevation (ft, NAVD-88)	Standard deviation (ft)	Vegetative community[a]	Data source[b]
1	-	-	1.25	-	OW	CS-21
2	0.73	0.05	1.29	0.15	OW	LGH (Humble)
3	1.10	0.00	1.35	0.12	OW	LGH (Humble)
4	0.65	0.07	0.87	0.08	OW	LGH (Humble)
5	-	-	1.16	0.08	OW	LGH (Humble)
6	0.80	0.16	1.32	0.24	OW	LGH (Humble)
7	0.62	0.10	0.83	0.09	OW	LGH (HWY 82)
8	0.63	0.12	1.18	0.29	OW	LGH (HWY 82)
9	1.22	0.15	1.31	0.12	FM	LGH (HWY 82)
10	1.27	0.18	1.35	0.16	FM	LGH (HWY 82)
11	0.81	0.14	1.03	0.13	OW	OD
12	1.06	0.18	1.24	0.21	OW	OD
13	1.14	0.16	1.37	0.15	OW	OD
14	0.83	0.10	1.06	0.12	OW	OD
15	1.39	0.13	1.52	0.06	OW	OD
16	0.72	0.10	1.14	0.14	OW	OD
17	0.61	0.10	0.73	0.10	FB	OD
18	0.76	0.12	1.08	0.13	OW	OD
19	1.20	0.05	1.18	0.21	OW	OD
20	0.88	0.18	1.26	0.16	OW	OD
21	0.92	0.16	1.15	0.11	OW	OD
22	0.80	0.16	0.95	0.18	OW	OD
23	0.77	0.09	1.06	0.20	OW	LGH (HWY 82)
24	1.36	0.12	1.48	0.14	OW	LGH (HWY 82)
25	1.01	0.16	1.50	0.07	OW	LGH (HWY 82)
26	0.95	0.17	1.36	0.26	OW	LGH (HWY 82)
27	0.82	0.12	1.19	0.13	OW	LGH (HWY 82)
28	0.77	0.16	1.15	0.19	OW	LGH (HWY 82)
Overall means	0.92	0.12	1.19	0.15		

a-Vegetative community key:
OW = Oligohaline wiregrass
FM = Fresh maidencane
FB = Fresh bulltongue

b-Data source key:
CS-21 = Hwy 384 Hydrologic Restoration Project - Marsh Elevation Survey.
LGH (Humble) = Lonnie G. Harper and Associates - The Chenier Plain Secondary GPS Network ME-11/PME-15 (Humble Canal).
LGH (HWY 82) = Lonnie G. Harper and Associates - The Chenier Plain Secondary GPS Network (ME-16 Highway 82 Freshwater Introduction).
OD = Original data from current study.

standard deviations of less than 0.15 ft. The exception to this was a fresh bulltongue marsh near the Schooner Bayou Structure that is substantially lower. This indicates that bulltongue may be more flood tolerant than some other species.

Marsh Flooding Analysis

The USACE operates the five perimeter control structures to prevent saltwater intrusion from navigation channels, to moderate water levels, and to allow for limited floodwater drainage. Each structure holds two data collection platforms (DCPs), one on each end of the structure, that record water level hourly. The data record described here covers the 14-yr period of 1987-2000. All hourly stage data were adjusted from the Mean Low Gulf (MLG) datum to the North American Vertical Datum 1988 (NAVD-88). The datum adjustments were based on elevation surveys taken in 2000 and 2001 of the interior and exterior lock staff gauges on each structure, by Lonnie G. Harper and Associates, Inc., of Grand Cheniere, Louisiana.

We were somewhat concerned that lock and control structure operation and the proximity of the DCPs to the structures might skew local stage readings, thereby reducing their reliability for the evaluation of marsh flooding. To address this issue, we compared the hourly water level record from a continuous data recorder (sonde) deployed for CWPPRA monitoring of the Highway 384 Hydrologic Restoration Project against the DCP stage readings on the interior (western) recorder of the Calcasieu Lock over the same 28-month period. The comparison produced a calculated correlations coefficient (r) of 0.83, which indicates a relatively high degree of correlation between the data sets. This gave us greater confidence that the stage readings at the control structures adequately reflect water elevations in adjacent marshes.

It is important to note that whenever locks are open for drainage, DCP stage readings at the structures are skewed downward because the slope of the water is reduced as water passes through the lock. This causes head differential calculations during drainage events to be reduced, resulting in a slight underestimation of the magnitude of drainage opportunities. This phenomenon has no effect on calculations of marsh surface flooding.

Prolonged Marsh Flooding

Prolonged flooding events can adversely affect wetland primary production and sustainability. Relating the DCP inside stage records to local marsh elevations enabled us to identify prolonged marsh-flooding events for all five structures over the period of record. For this evaluation, prolonged flooding was defined as marsh flooding events that lasted longer than 30 consecutive days. Flood tolerance in wetland vegetation is species specific, and plant response is highly variable and strongly dependent on soil chemistry (i.e., salinity, sulfide and iron concentration). Thus, there is no well-defined period that can be used as a measure of the flood duration that causes substantial plant stress. We selected a period of 30 days for this analysis based on studies conducted in comparable marsh types that are described later. Often during these prolonged flooding events, water level dipped below the average marsh elevation for brief periods (a few hours to a couple of days). When this occurred, we treated these brief periods of marsh surface exposure conservatively by continuing to count them as flooding events, based on an assumption that such brief interludes of surface exposure offered limited opportunity for the marsh substrate to respond or to recover to more aerobic conditions. Three of the five control structures evaluated, the Calcasieu Lock and the Catfish Point and Schooner Bayou control structures, underwent periods where the marsh was flooded for more than 30 consecutive days (Figure 11). By far the most dramatic and prolonged marsh flooding occurred at the Catfish Point Control Structure, where the marsh was flooded in the vast majority of the readings.

Marsh Flooding and Drainage Opportunities

We compared simultaneous inside and outside stage readings for each structure to determine the frequency and magnitude of available water level differential (head) where gravity drainage would be possible. Inside stage readings for each structure were plotted against local marsh elevations as determined by survey. We then evaluated resulting hydrographs (Appendix A) to determine marsh flooding durations and wetland drainage potential on an annual time scale. Figures 12-17 summarize annual marsh flooding regimes and gravity drainage potential at each of the five USACE structures. Analyses of drainage opportunities were limited only to those periods when the inside stage exceeded local average marsh elevation and favorable head for drainage existed (i.e., the marsh was flooded and drainage head existed). To aid data interpretation, we divided drainage opportunities into four categories of head differential (HD) by 0.25-ft (3-in) increments:

HD> 0 $\leq$ 0.25 ft
HD> 0.25 ft $\leq$ 0.5 ft
HD> 0.5 ft $\leq$ 0.75 ft
HD> 0.75 ft

In the following section, we summarize general observations from this analysis for each water control structure.

Calcasieu Lock . Oligohaline wiregrass marshes in this area were flooded in more than 50% of the readings during only one of the 14 years recorded (Figure 12). There was some opportunity for drainage during most of the flooding events. Over the period of record, four marsh flooding events exceeded 30 consecutive days, with the longest event, during 1991-92, lasting 92 consecutive days (Figure 11). Head differential analysis indicated that the majority of drainage opportunities fall in the HD > 0 $\leq$ 0.25 ft category (Figure 12). Drainage opportunities in the other head differential categories are relatively evenly distributed. The marsh elevation used in the analysis was 1.25 ft NAVD-88 based on available surveys in the vicinity of Calcasieu Lock. A post-data analysis marsh elevation survey funded by CWPPRA in the western half of the Lakes Sub-basin identified an average marsh elevation of 1.12 ft NAVD-88 with a standard deviation of 0.31 ft.

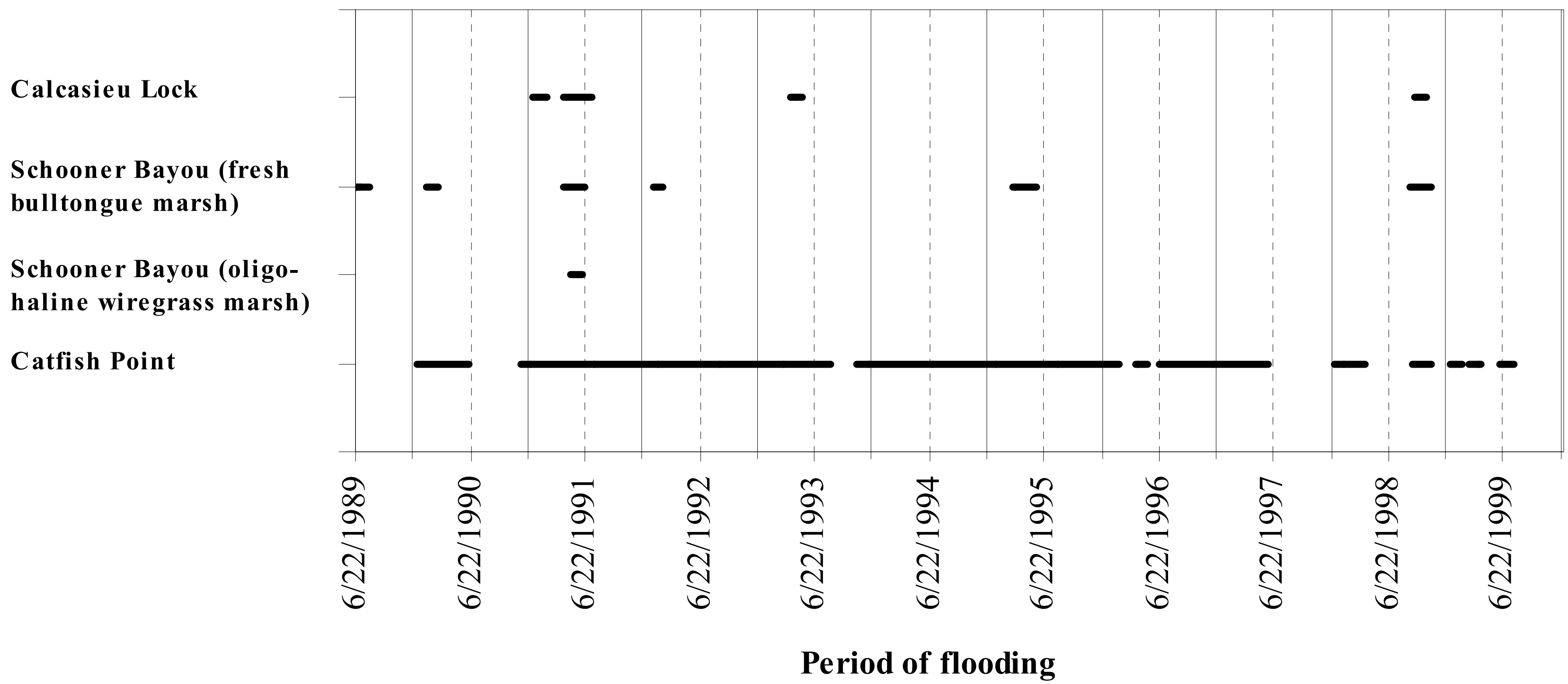


Figure 11. Flooding events that exceeded 30 consecutive days at marshes in the vicinity of Calcasieu Lock, Catfish Point Control Structure, and Schooner Bayou Control Structure. These prolonged flooding events were not noted at the Freshwater Bayou or Leland Bowman locks.

Calcasieu Lock

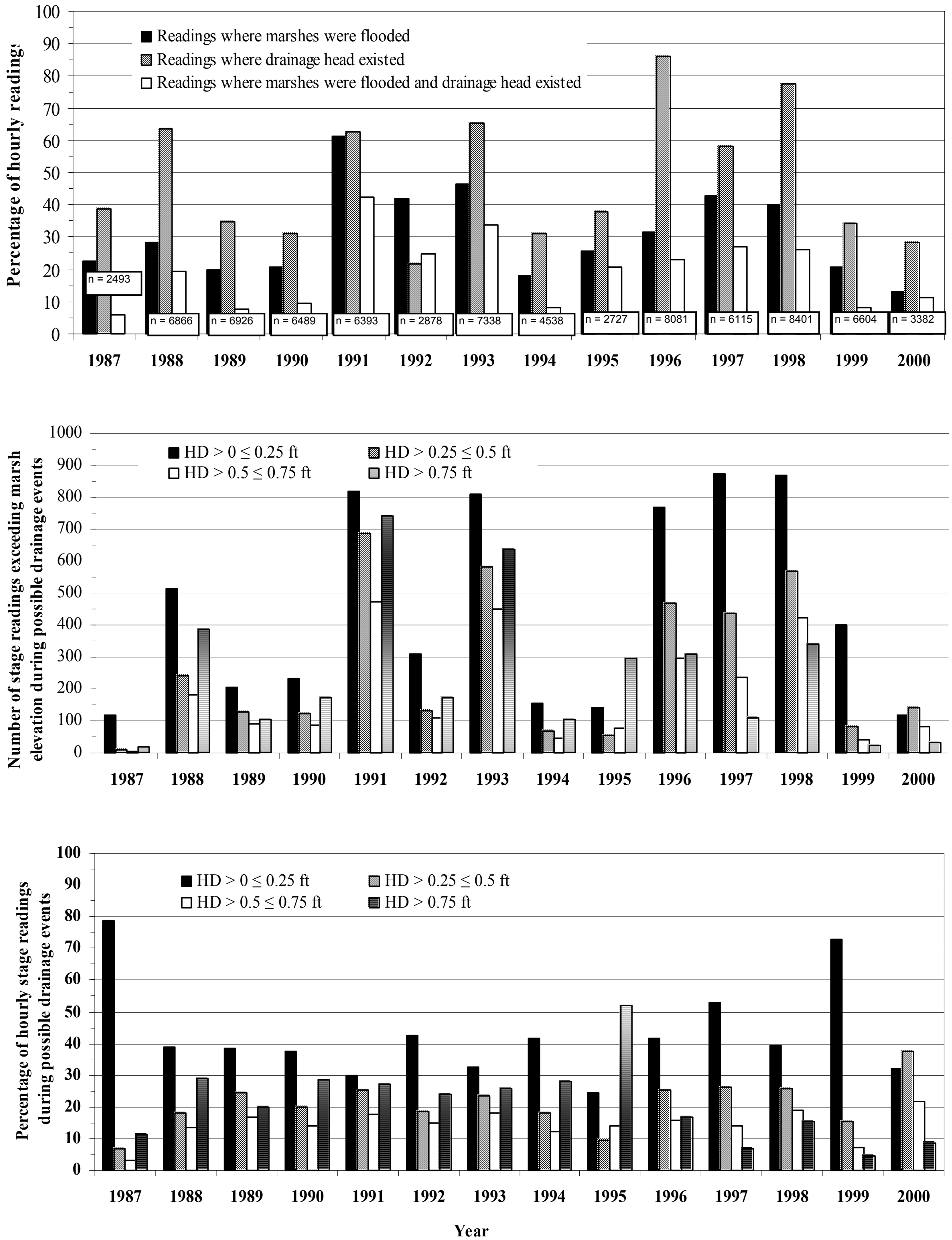
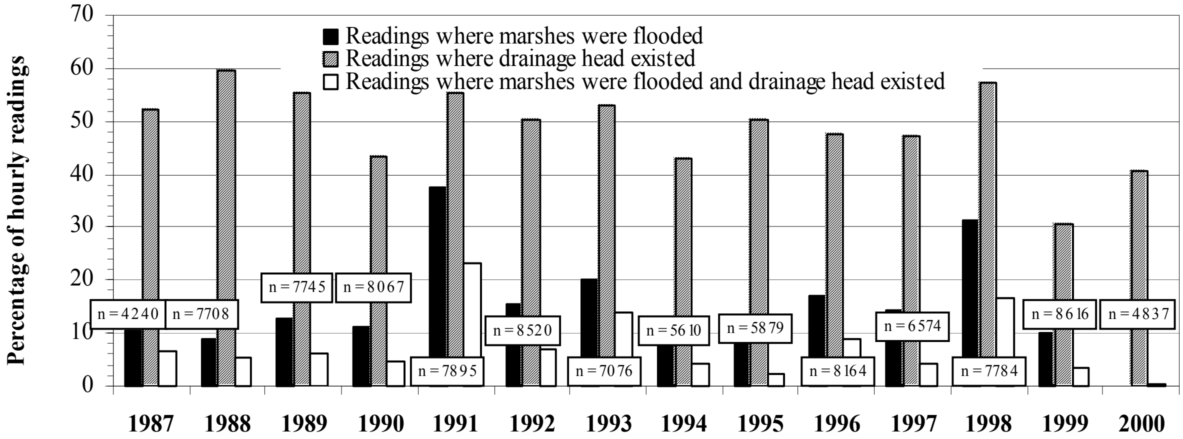
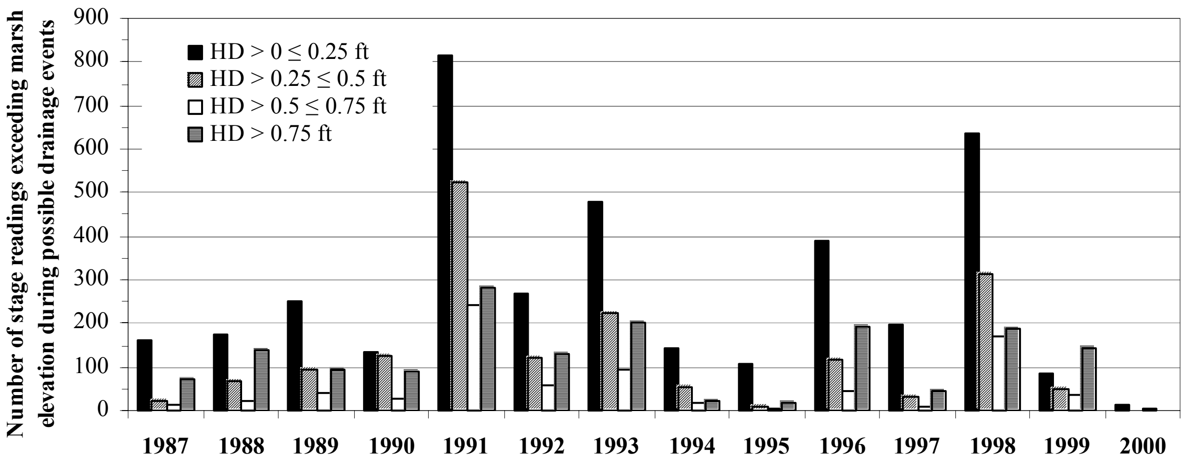


Figure 12. Marsh flooding and head differential (HD) summary statistics for the Calcasieu Lock, 1987-2000.

Leland Bowman Lock





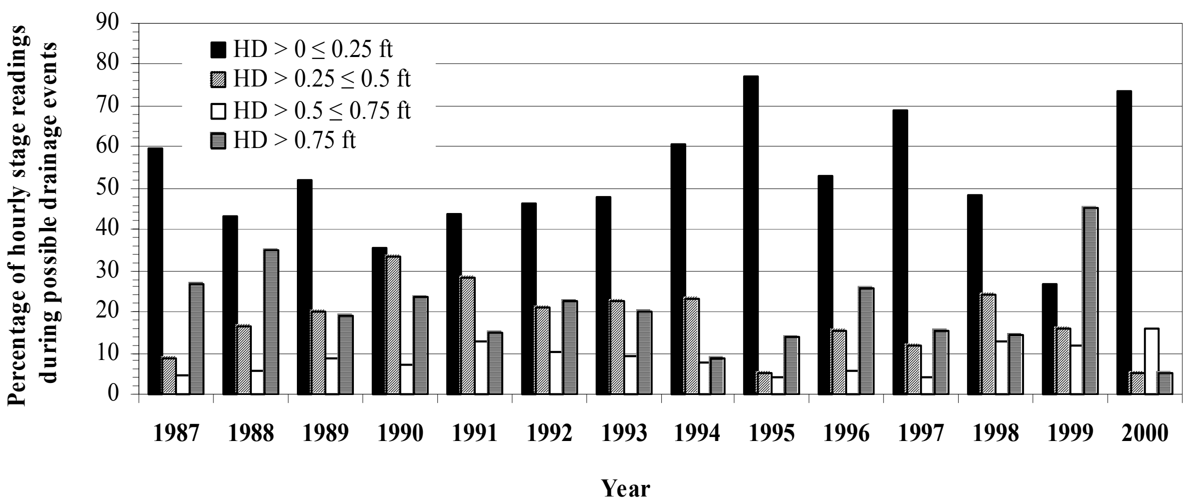


Figure 13. Marsh flooding and head differential (HD) summary statistics for the Leland Bowman Lock, 1987-2000.

Schooner Bayou - Oligohaline wiregrass

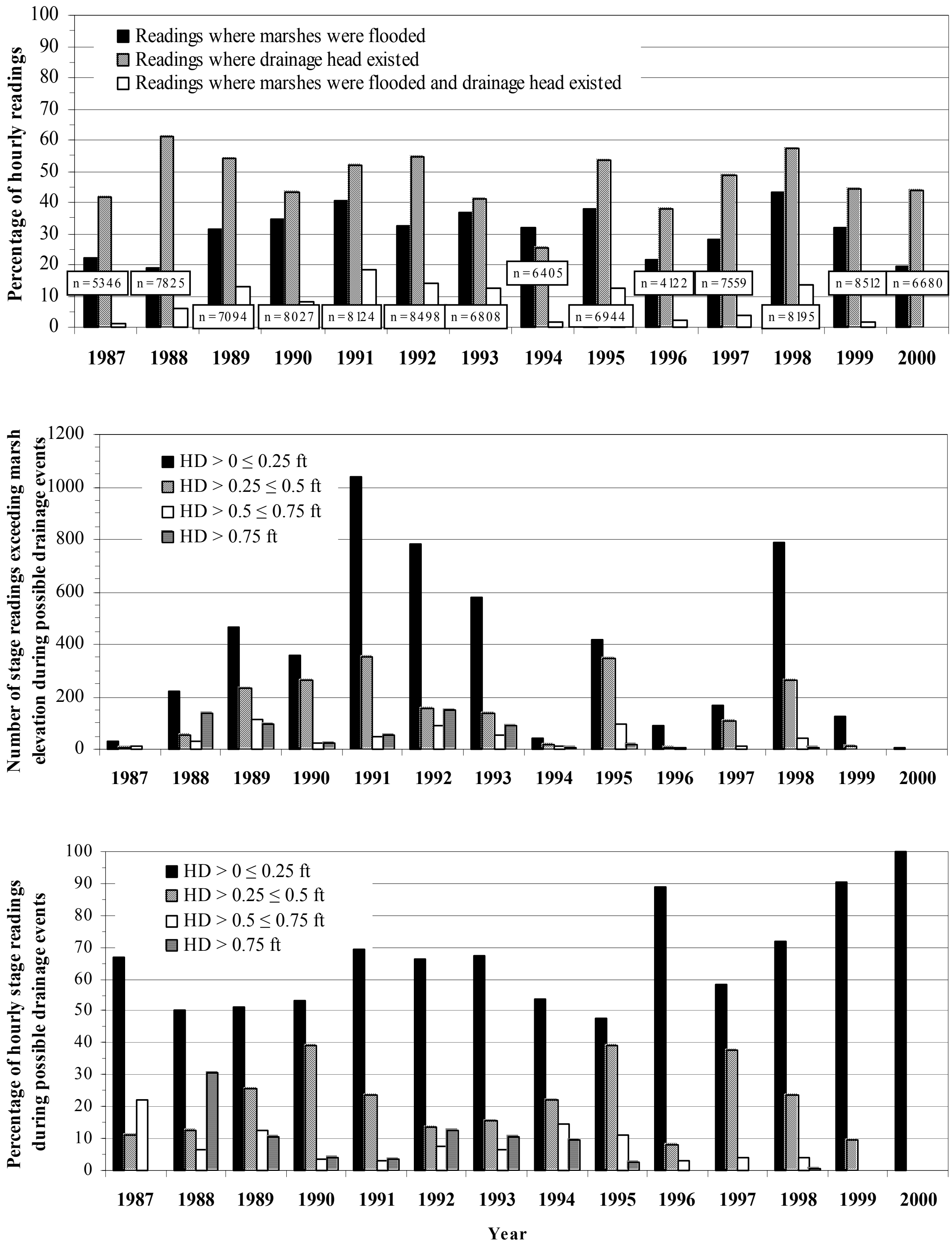


Figure 14. Marsh flooding and head differential (HD) summary statistics for the oligohaline wiregrass marsh near the Schooner Bayou Control Structure, 1987-2000.

Schooner Bayou - Fresh bulltongue

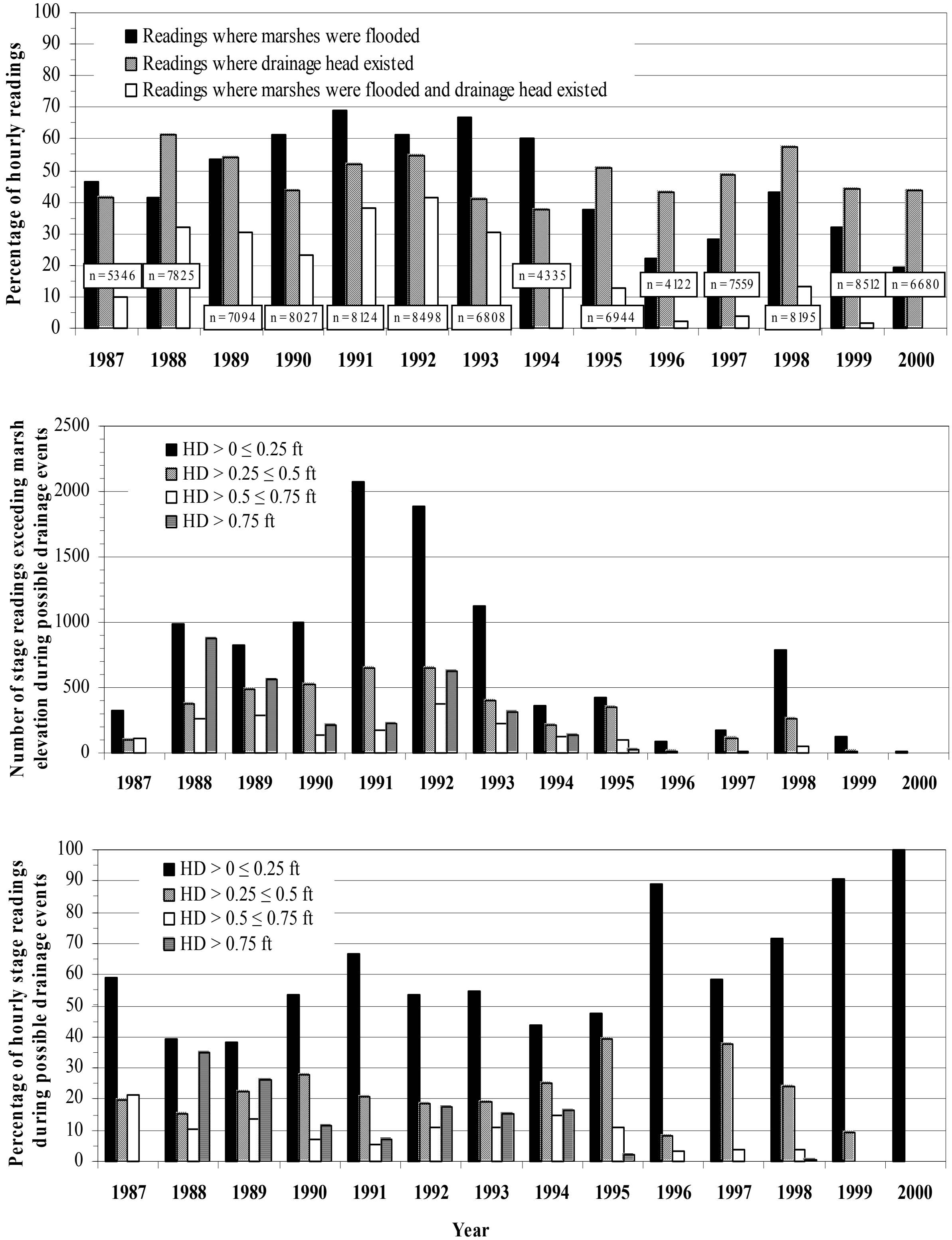


Figure 15. Marsh flooding and head differential (HD) summary statistics for the fresh bulltongue marsh near the Schooner Bayou Control Structure, 1987-2000.

Freshwater Bayou Lock

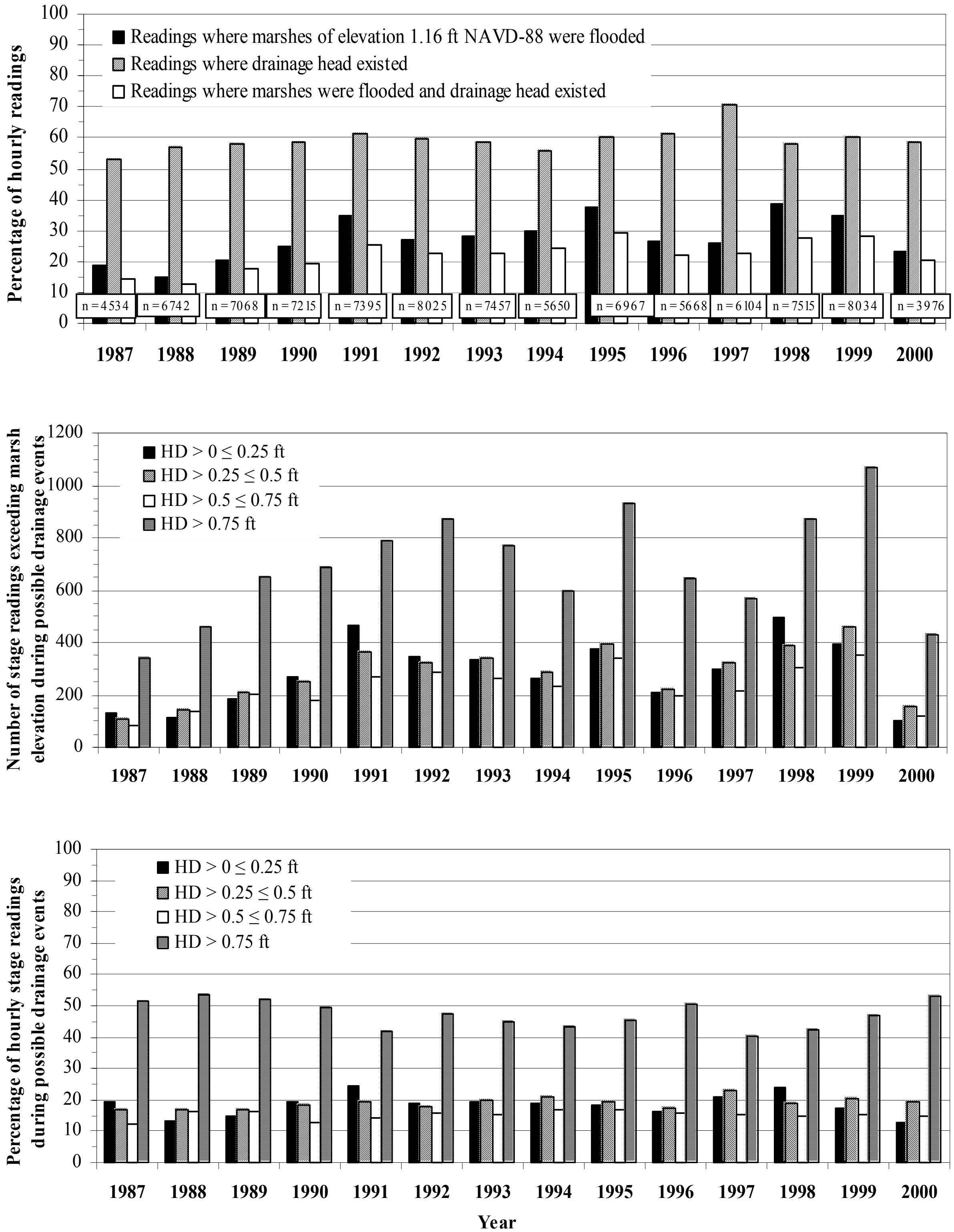


Figure 16. Marsh flooding and head differential (HD) summary statistics for the Freshwater Bayou Lock, 1987-2000.

Catfish Point Structure

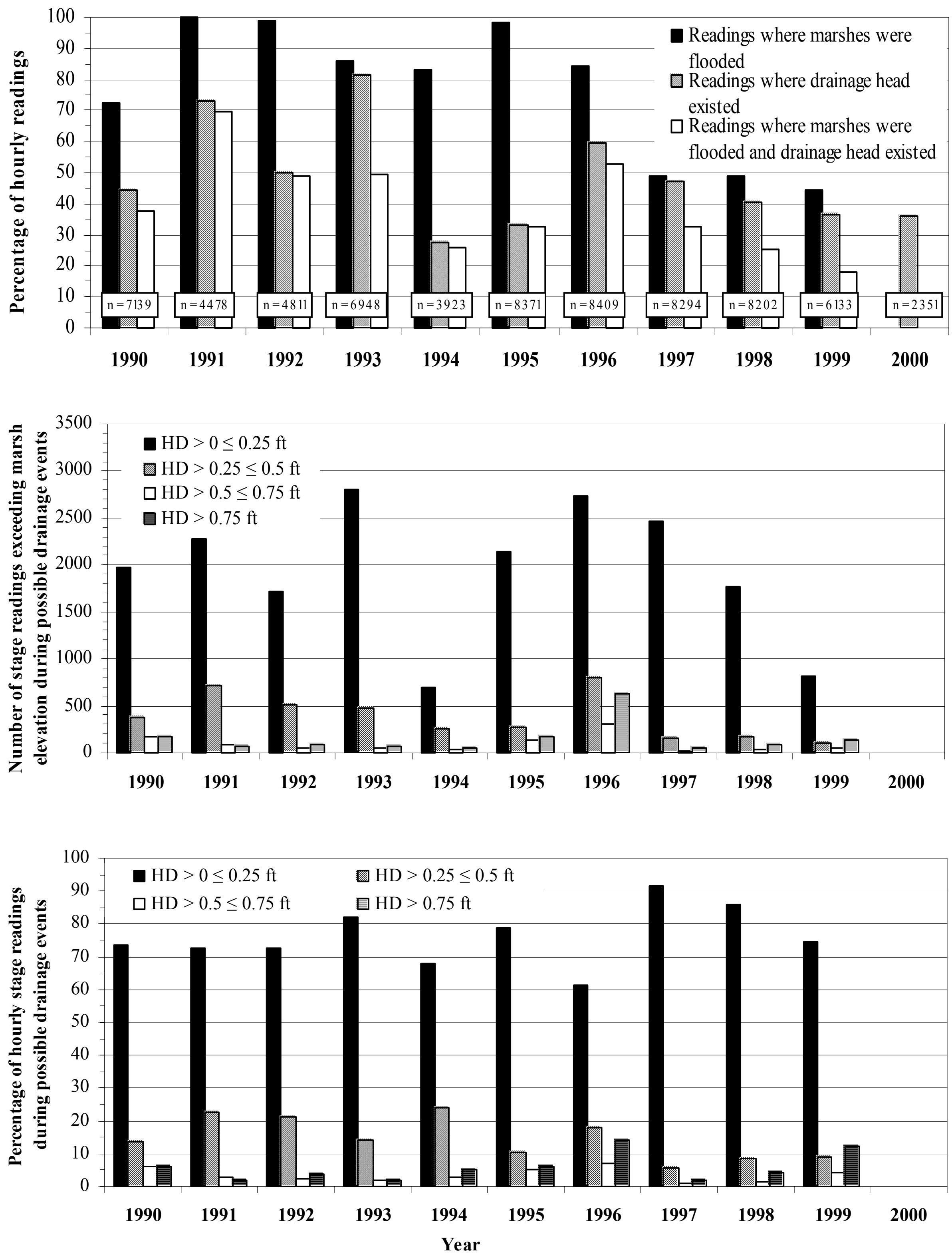


Figure 17. Marsh flooding and head differential (HD) summary statistics for the Catfish Point Control Structure, 1987-2000.

Leland Bowman Lock. In two of 14 years, oligohaline wiregrass marshes in the area were flooded in more than 30%, but never more than 40%, of the readings (Figure 13). The record revealed no prolonged flooding events that exceeded 30 days. Head differential analysis indicated that the majority of the readings where favorable drainage head existed fall in the HD > 0 $\leq$ 0.25 ft category, and to a smaller extent in the HD > 0.25 ft $\leq$ 0.5 ft category (Figure 13).

Schooner Bayou Control Structure. In two of 14 years, oligohaline wiregrass marshes in this vicinity flooded in more than 40% of the readings, but never in more than 50% of the readings (Figure 14). The record revealed a single prolonged flooding event that exceeded 30 days, in 1991 (Figure 11). Head differential analysis indicates that the majority of the readings where favorable drainage head existed fall in the HD > 0 $\leq$ 0.25 ft category and, to a smaller extent, in the HD > 0.25 ft $\leq$ 0.5 ft category (Figure 14).

It is noteworthy that the single fresh bulltongue marsh site that we surveyed was almost 0.5 ft lower on average than the oligohaline wiregrass marsh (Table 5, site 17, and Figure 11). Only one of seven elevation data collection stations in the vicinity of the Leland Bowman and Schooner Bayou structures was taken in this community. Assuming that this elevation difference could have a profound impact on marsh flooding regimes and plant health, we treated this site independently from the other sites where the marsh elevations were collectively averaged. Additional survey data would help us determine if elevations at this site are typical of all fresh bulltongue marshes in the Mermentau Lakes Sub-basin.

In striking difference to the adjacent oligohaline wiregrass marsh, we noted that in four of the 14 years, fresh bulltongue marshes near the Schooner Bayou Control Structure were flooded in 60-70%, of the readings (Figure 15). The record revealed six prolonged flooding events that exceeded 30 days over the period of record (Figure 11). Head differential analysis indicated that the majority of the readings where favorable drainage head existed fall in the HD > 0 $\leq$ 0.25 ft category and to a smaller extent in the HD > 0.25 ft $\leq$ 0.5 ft category (Figure 15). Fresh bulltongue marshes are well documented as very flood tolerant (McKee and Mendelssohn 1989; Howard and Mendelssohn 1995; Grace and Ford 1996).

Upon noting the seemingly large difference in elevation between these adjacent marsh types at the Schooner Bayou Control Structure, we thought it relevant to determine any major differences in salinity regime. We accomplished this by using salinity and water level data from the Freshwater Bayou Hydrologic Restoration Project (LDNR 2001). This project has a continuous water level and salinity recorder located in the oligohaline wiregrass marsh near survey site 15 (Figure 10). We also reviewed discrete salinity records—monthly readings taken over four years—from monitoring stations in close proximity to elevation site 16, in the oligohaline wiregrass marsh, and site 17, located in the fresh bulltongue marsh. The salinities in the fresh bulltongue marsh were consistently lower than salinities in the oligohaline wiregrass marsh, at times by more than 10 ppt. The only exceptions to this trend occurred when all stations were fresh or nearly fresh (0-2 ppt). The differences in elevation between the oligohaline wiregrass marsh and the fresh bulltongue marsh, coupled with the large differences in salinity regime over such a short distance, emphasize the importance of protecting this low-lying fresh marsh from saltwater intrusion. If the fresh bulltongue marsh in this area is lost because of navigation channel-induced saltwater intrusion, it appears unlikely that, with its low elevation, the fresh marsh would convert to a mesohaline wiregrass marsh habitat. The greater likelihood is that these marshes will convert to a less productive shallow pond habitat.

Freshwater Bayou Lock. The 14-yr record at Freshwater Bayou Lock indicated that the *Spartina patens*-dominated marshes were flooded in more than 30% of the readings in four years, and never in more than 40% of the readings for any given year (Figure 16). The record revealed no prolonged flooding events that exceeded 30 days. In sharp contrast to the other USACE structures, head differential analysis at Freshwater Bayou Lock indicated that the majority of the readings where favorable drainage head existed fell in the HD > 0.75 ft category and were relatively evenly distributed in the other categories (Figure 16). This indicates that marsh drainage potential at the Freshwater Bayou Lock exceeds that of the other control structures.

Catfish Point Control Structure. Over the 10-yr period 1990-2000, marshes near Catfish Point were flooded substantially more than marshes at any of the other control structures (Figure 17). Data reveal that in three of the 10 years, marshes were flooded nearly all of the time. Ten prolonged flooding events exceeded 30 days over the period of record (Figure 11). Analysis of the prolonged flooding revealed that between December 1990 and June 1996, the marsh was flooded more than 92% of the time. Since 1997, the marshes have been flooding generally less than 50% of the time; however, periods of prolonged flooding still appear to dominate marsh inundation and exposure processes. Head differential analysis reveals that the vast majority of the readings where favorable drainage head existed fall in the HD $> 0 \leq 0.25$ ft category (Figure 17). These data indicate that, despite the apparent high water in the vicinity of the Catfish Point Control Structure, it is very difficult to drain these marshes because very low drainage head differentials are so prevalent.

The biotic impact of the prevailing hydrology at Catfish Point is unclear. Prolonged flooding in the area may increase marsh edge erosion and could stress less flood-tolerant species. However, land loss imagery indicates that there has been very little land lost in this area since 1978 and that the area seems relatively stable, with very small and site-specific areas of loss and gain.

Historical Habitat Shifts in the Mermentau Basin

Half a century ago, the Mermentau Basin was vegetatively very different than it is now. Vegetative type maps show that the region's wetlands were formerly characterized by broad expanses of marshes dominated by saw grass *(Cladium jamaicense*), with other freshwater, intermediate, and brackish sub-dominants such as leafy three square (*Schoenoplectus robustus*), Olney's bulrush (*Schoenoplectus olneyi*), and bulltongue (*Sagittaria lancifolia*), which are characteristic of a low-salinity estuary. There were relatively few areas of open water, excluding Grand Lake and White Lake (O'Neil 1949). We utilized O'Neil's (1949) vegetative type map as a baseline to characterize wetland habitat shifts that have occurred over a nearly 50-yr period. Hydrologic alterations such as the construction of the CSC, Freshwater Bayou Canal, and GIWW have led to significant losses of these wetland habitats through saltwater intrusion. By 1968, much of this habitat had been lost when Robert Chabreck first began a series of vegetative and habitat surveys (Chabreck 1972). During repeat flyovers of the transects in 1978 and 1988, transitions in habitat type were delimited to produce habitat type maps for those years. In 1997, Chabreck and Linscombe revisited the same transects as in 1968, though their sampling regime differed somewhat from that of Chabreck's earlier work (Chabreck et al. 1968; Chabreck and Linscombe 1997).

We analyzed historical habitat shifts over the years 1949, 1968, 1978, 1988, and 1997 using digital versions of coastal vegetation maps produced from coastwide vegetative mapping efforts (O'Neil 1949; Chabreck et al. 1968; Chabreck and Linscombe 1978, 1988, 1997). These data are not accurate for showing detailed changes in land-water ratios, but they present a good composite of how wetland habitat types have changed over time.

Figure 18 illustrates the types of habitats identified during each of the mapping years and the direction of habitat shifts toward either fresher or more saline conditions for each of the years compared. For consistency, we reclassified O'Neil (1949) vegetation categories into the four marsh type categories used in the other vegetative type maps (i.e., fresh, intermediate, brackish, or saline), based on the dominant species that O'Neil (1949) noted in each area (Table 6).

Habitat shifts in the Mermentau Basin from 1949 through 1997 show a long-term trend toward freshening of the Lakes Sub-basin, and increasing salinity in much of the Chenier Sub-basin (Figure 18). Most of the managed areas of the Rockefeller Wildlife Refuge, and the marshes south and southeast from Pecan Island, do not share the general trend of increasing salinity that dominates the Chenier Sub-basin. The different trend in habitat shifts in these areas is presumably explained by wetland management efforts on the Rockefeller Wildlife Refuge coupled with increased freshwater influence from the Atchafalaya River.

Substantial variability in habitat types is evident from one comparison period to the next. The 1949-68 comparison reflects the loss of the saw grass (*Cladium jamaicense*) marsh as the predominant marsh community. Although saw grass marsh was classified as intermediate in 1949, by 1968 saw grass was largely absent in the Mermentau Basin, and plant communities had shifted to dominant species typical of the fresh marsh (Figure 18). The 1968-78 and 1978-88 comparisons reveal site-specific shifts toward both more saline and fresher marsh types, with the latter decade dominated by shifts toward higher salinities. This trend was reversed over the period 1988-97, when, in large part, the areas that previously converted from fresh to intermediate shifted back toward a fresh marsh type. This comparison between survey periods also exemplifies the impoundment effect of the USACE control structures, and the increasing influence of marsh management activities and restoration projects, as well as the increasing influence of the Atchafalaya River in the eastern, southern, and southeastern portions of the basin.

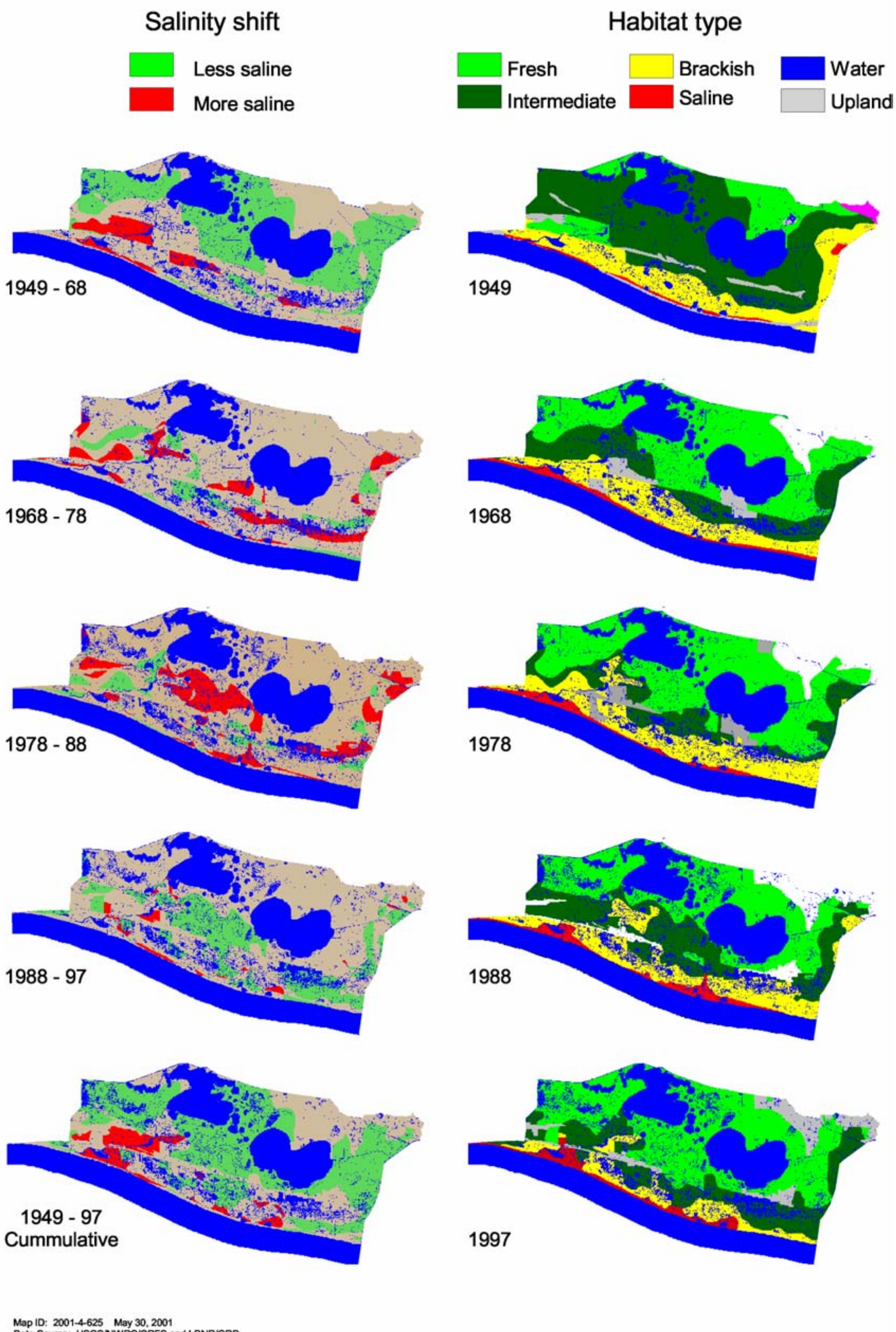


Figure 18. Wetland habitat and salinity shifts based on historical vegetative surveys of the Mermentau Basin.

Table 6. Wetland habitat reclassification of the O'Neil (1949) vegetation map based on documented vegetation species.

O'Neil (1949) habitat type	Dominant vegetation	Reclassified habitat type
Fresh water marsh	Maidencane (*Panicum hemitomon*) Cattail (*Typha* spp.) Bulltongue (*Sagittaria lancifolia*) Spikerush (*Eleocharis* spp.) Giant cutgrass (*Zizaniopsis miliacea*) Saw grass (*Cladium jamaicense*) Roseau cane (*Phragmites australis*) California bulrush (*Schoenoplectus californicus*) Softstem bulrush (*Schoenoplectus tabernaemontani*)	Fresh marsh
Floating fresh marsh	Maidencane (*Panicum hemitomon*)	Fresh marsh
Excessively drained salt marshes	Smooth cordgrass (*Spartina alterniflora*) Wiregrass (*Spartina patens*) Black needle rush (*Juncus roemerianus*)	Saline marsh
Brackish three-cornered grass marsh	Freshwater three-square (*Schoenoplectus americanus*) Wiregrass (*Spartina patens*)	Brackish marsh
Floating three-cornered grass marsh	Freshwater three-square (*Schoenoplectus americanus*)	Intermediate marsh
Intermediate marsh	Saw grass (*Cladium jamaicense*) Cattail (*Typha* spp.) Roseau cane (*Phragmites australis*) California bulrush (*Schoenoplectus californicus*) Softstem bulrush (*Schoenoplectus tabernaemontani*) Freshwater three-square (*Schoenoplectus americanus*) Wiregrass (*Spartina patens*) Bulltongue (*Sagittaria lancifolia*) Hogcane (*Spartina cynosuroides*)	Intermediate marsh
Leafy three-cornered grass or coco marsh	Leafy three-square (*Schoenoplectus robustus*) Wiregrass (*Spartina patens*) Hogcane (*Spartina cynosuroides*)	Brackish marsh
Saw grass marsh	Saw grass (*Cladium jamaicense*) Cattail (*Typha* spp.) Roseau cane (*Phragmites australis*) California bulrush (*Schoenoplectus californicus*) Softstem bulrush (*Schoenoplectus tabernaemontani*) Bulltongue (*Sagittaria lancifolia*) Hogcane (*Spartina cynosuroides*) Giant cutgrass (*Zizaniopsis miliacea*) Spikerush (*Eleocharis* spp.)	Intermediate marsh
Sea rim		Non-marsh